SERI/TR-635-967
UC Category: 60

Environmental Noise Levels at the DOE MOD-2 Wind Turbine Located at Goodnoe Hills, Washington

December 1982

Prepared Under Task No. 1066.70
WPA No. 171

Solar Energy Research Institute
A Division of Midwest Research Institute

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Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

FOREWORD

This report details the characteristics of the natural acoustic background present at and near the Bonneville Power Administration (BPA) Wind Energy Test Site at Goodnoe Hills, Wash., in October 1980. The objective of this study was to benchmark the existing acoustic background at the test site and at other locations in the vicinity before installation and subsequent operation of the cluster of three DOE/NASA MOD-2 wind turbines.

The field measurements and analysis were performed by Edward McKenna of the SERI Wind Energy Branch, Richard Garrelts of the Measurement Design and Support Branch, and David Miles of Colorado State University. The assistance of Jack Elwood of the BPA and members of the Boeing Engineering and Construction Company in performing the field measurements is gratefully acknowledged.

We gratefully acknowledge the hospitality and logistical assistance, including electric power and shelter for the instrumentation, provided by the BPA and the Boeing Engineering and Construction Company at the MOD-2 site.

We also appreciate the hospitality and assistance, including electric power for instrumentation, provided by Robert Imrie and J. E. Fuhrman of Goldendale, Wash. Finally, we wish to thank the U.S. Environmental Protection Agency, Region X, Noise Control Program, for the loan of their sound level measuring instrumentation that permitted the extension of monitoring locations.

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NOMENCLATURE

Abbreviations

B&K	Bruel and Kjaer, manufacturers of acoustic measuring equipment
BPA	Bonneville Power Administration
CNA	Community Noise Analyzer, an acoustic monitoring device
DOE	Department of Energy
EPA	Environmental Protection Agency
GenRad	manufacturers of acoustic measuring equipment
NASA	National Aeronautic and Space Administration
SERI	Solar Energy Research Institute
SLC	sound level calibrator
SLM	sound level meter

Units and Symbols

dB	decibel
dB(A)	decibel, A-weighted
L	fast, A-weighted SPL
L_x	SPL exceeded x-percent of time
L_{eq}	equivalent continuous sound level
L_{dn}	day-night average sound level
L_d	day (0700-2200 hours) average sound level
L_n	night (2200-0700 hours) average sound level
RSS	root sum squared averaging:

$$RSS_j = \left(\sum_i X_{ij}^2\right)^{1/2},$$

where X_{ij} are the dB levels at each frequency j for each spectrum i.

SPL	sound pressure level, in dB(A)

See Appendix A for more detailed descriptions of the various acoustic terms.

SECTION 1.0

INTRODUCTION

As part of the DOE/SERI Wind Energy Noise Studies Task goal to document the acoustic output associated with the operation of large utility-grade wind turbines, field measurements were undertaken to measure and document the acoustic background levels existing at and around the Bonneville Power Administration (BPA) Wind Turbine Site located at Goodnoe Hills, Wash. Three DOE/NASA Boeing model MOD-2 wind turbines are to be erected at the BPA site.

The specified objective for the measurements, undertaken from 17 June to 20 June 1980, was to establish the acoustical background for the BPA site over a frequency range of 0.1 Hz to 20,000 Hz. This survey included the measurement of sound levels in the vicinity of the BPA meteorological (met) tower, as well as locations at distances of 4.3 km and 7.6 km from the BPA met tower. The measurements taken were sufficient to determine the environmental levels for both audible noise (20 Hz to 20,000 Hz) and infrasound (inaudible sounds in the frequency range 0.1 Hz to 30 Hz).

The acoustic survey was conducted at the request of NASA Lewis Research Center for the BPA, under Federal Environmental Protection Agency (EPA) Noise Survey Guidelines. These guidelines require a minimum of 72 hours of data be collected at the site and that a minimum of one 24-hour period be included in that 72 hours. While sufficient data were obtained on acoustic data tapes to calculate the combined day-night level (L_{dn}) value for the met tower site, the actual calculations were not performed.

We made no attempt to characterize all sounds recorded by their precise source; rather, we considered them as natural acoustic sources generated in the area. EPA guidelines relate only to audible sounds; the infrasound analysis was included at the request of NASA Lewis based on previous experience with the acoustic output of wind turbines.

This report details the methods and results of the background acoustic survey conducted at the BPA site. Section 2.0 discusses the measurement sites. Instrumentation used for the survey is discussed in Sec. 3.0. Section 4.0 presents our analysis and results, and our conclusions and suggestions for future studies are given in Sec. 5.0.

SERI

SECTION 2.0

SITE DESCRIPTION

From 17 June to 20 June 1980, we measured infrasound and audible noise levels at the BPA met tower site, designated Site #1, and at two far field locations, designated Sites #2 and #3. The photographs in Fig. 2-1 illustrate the general nature of the terrain in the area. Figure 2-2 shows the BPA site and the surrounding areas, including the location of Sites #2 and #3. The locations are described below.

2.1 GENERAL AREA

The MOD-2 wind turbine sites are located on a ridge overlooking the Columbia River Valley in Section 33 of T3N, R17E, just off the Goldendale-Goodnoe Hills Road in southern Washington. The elevation ranges from 744 m to 805 m, with an average slope of 2 degrees. The location is the highest point in an 8-km radius, except for a small 810-m knoll 1.6 km to the east. Consequently, the perspective from the site is extensive.

To the north and west of the BPA site, the land slopes downward, forming a deciduous drainage that empties into Rock Creek, approximately 5 km northwest of the site. From the north to the southwest, the primary landforms are plateaus cut sharply by intermittent creeks, draining eventually into Rock Creek. The Columbia River Valley loops east to west to the south of the BPA site. In this direction the land drops off rapidly to the river level.

2.2 BPA MET TOWER (SITE #1)

The BPA meteorological station at the Goodnoe Hills site is located on a northwest sloping portion of the ridge. Slopes over short distances are less than 10 degrees. The ground cover consists of native grasses, sagebrush, and small rocks. There are occasional rock outcroppings protruding less than 1.5 m above the ground surface. Sounds from two construction sites approximately 300 m from the measuring location affected measurements during working hours (0700 to 1800 hours) but had no effect during other times.

Meteorological data--temperature, wind direction, and wind speeds at various heights on the met tower--were read from the strip chart recorders located in the meteorology data van at Site #1. The wind speed at 45 m was between 3 and 7 m/s during the survey.

2.3 RANCH HOUSE (SITE #2)

Measurement Site #2 was a wheat field to the east of a ranch house 7.2 km southeast of the BPA site. See Fig. 2-2 for the location and Fig. 2-3 for a topographic cross section. The site is located on a relatively level portion of the northwest corner of Sec. 18 of T3N R13E.

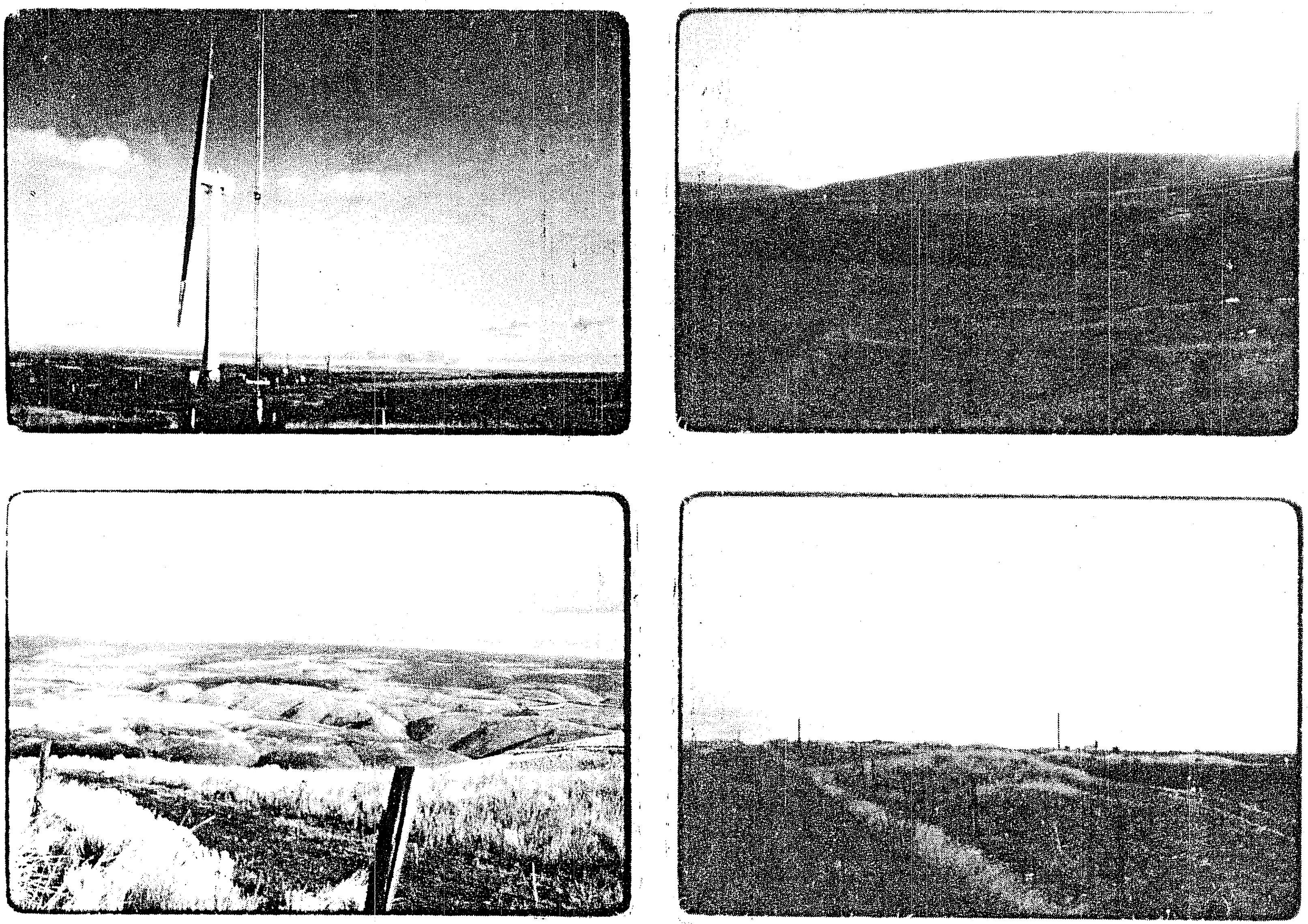

Figure 2-1. Photographs Illustrating the General Terrain Surrounding the Site, with Turbine #1 Shown in the Photograph at the Upper Left

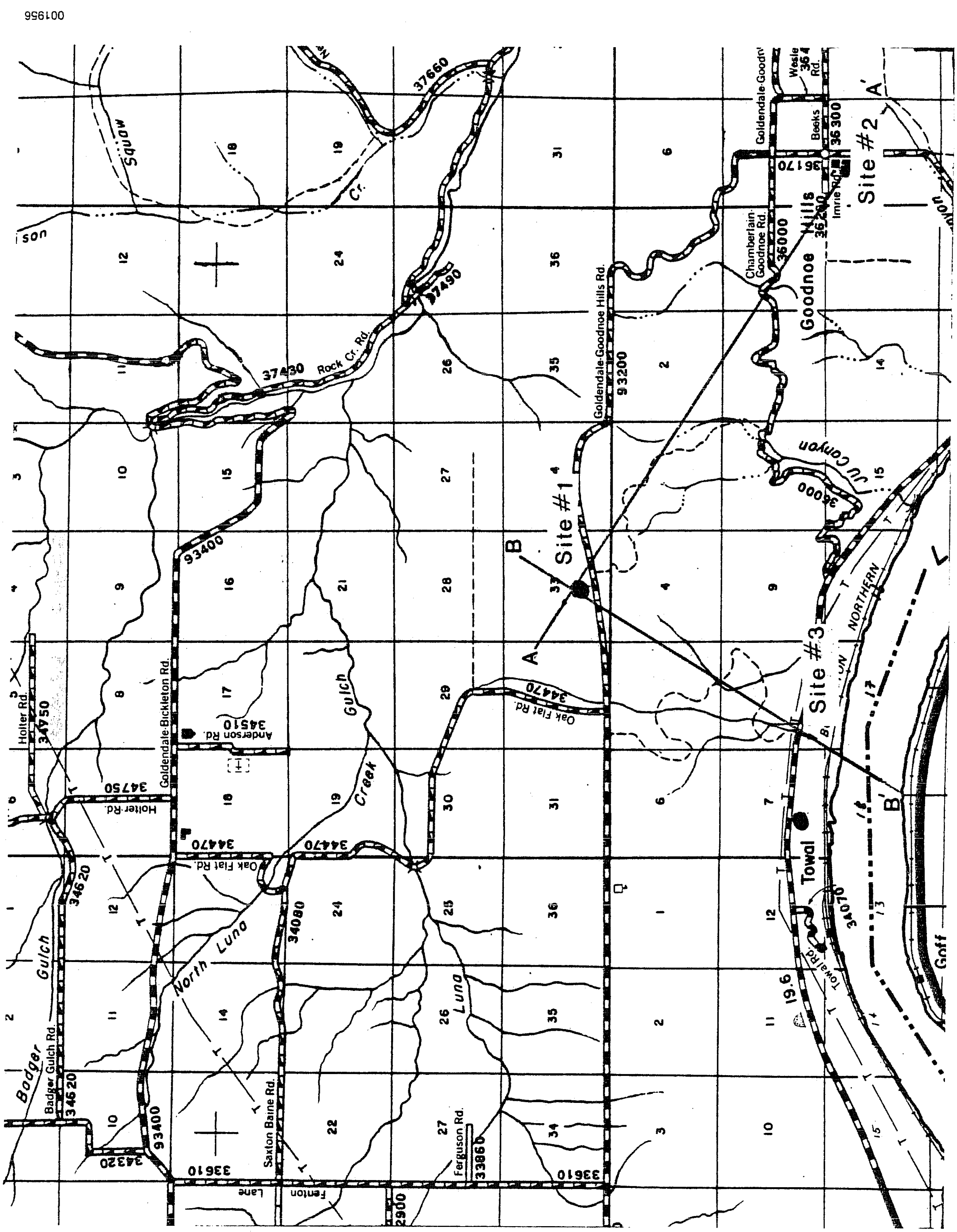

Figure 2-2. BPA MOD-2 Site and Surrounding Area

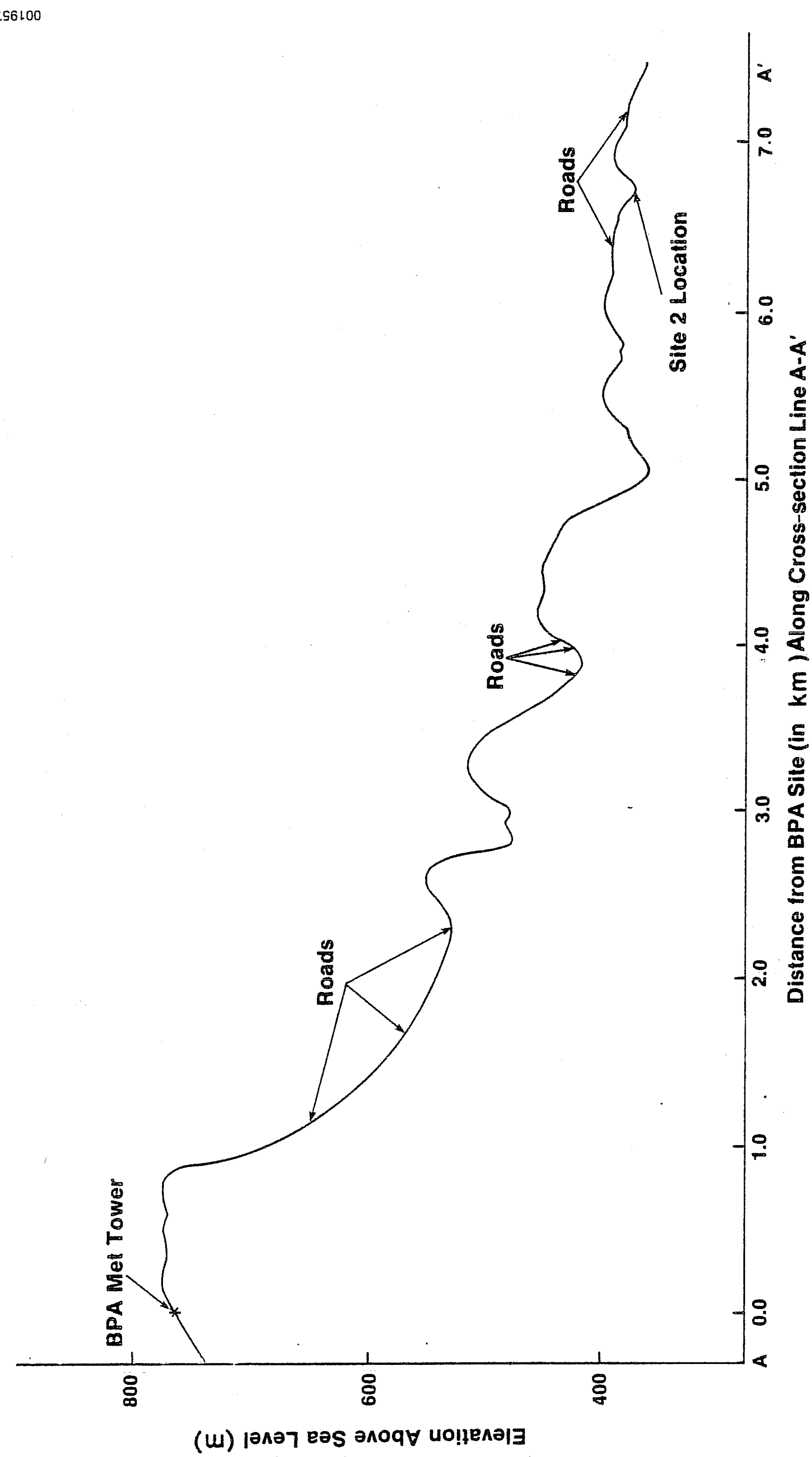

Figure 2-3. Topographic Cross Section A-A'

Although the area immediately around the site is rather level, the slope of the surrounding land is steep. From the west to the northeast, the topography is dominated by the ridge. Rock Creek and the Columbia River lie 4 km to the south-southwest. The land beyond these drainages consists of gently sloping plateaus cut by small intermittent streams. Cultivated rolling hills are within 2 km of the ranch house.

The primary source of noise of this location was a herd of corralled cattle located 150 m west of the measurement site. The cattle settled down around 2200 hours. Noise also was produced by a windbreak of deciduous trees surrounding the ranch house. These trees were approximately 24 m tall and 90 m west of the microphones.

2.4 RANCH HOUSE (SITE #3)

The third site monitored was an open space to the northeast of a ranch house 4 km southwest of the BPA site. See Fig. 2-2 for the location and Fig. 2-4 for a topographical cross section. The house lies on a plateau, 50 m above the Columbia River in Sec. 8 of T3N R8E.

The ground slopes gently 300 m to the south before dropping off sharply to the river. To the north the land slopes gently for 150 m before rising quite steeply to the ridge (16-degree slope).

The primary source of noise was the highway, which passed 120 m north of the microphones. Traffic was heavy until 0200 hours. Two railroad tracks follow the Columbia River, one on either side. They were 600 and 1520 m away from the microphones. Trains on the two tracks could be heard, but were indistinguishable from one another. Birds and cattle began making noise around 0600 hours. A small pump house located near the microphone produced no noticeable noise.

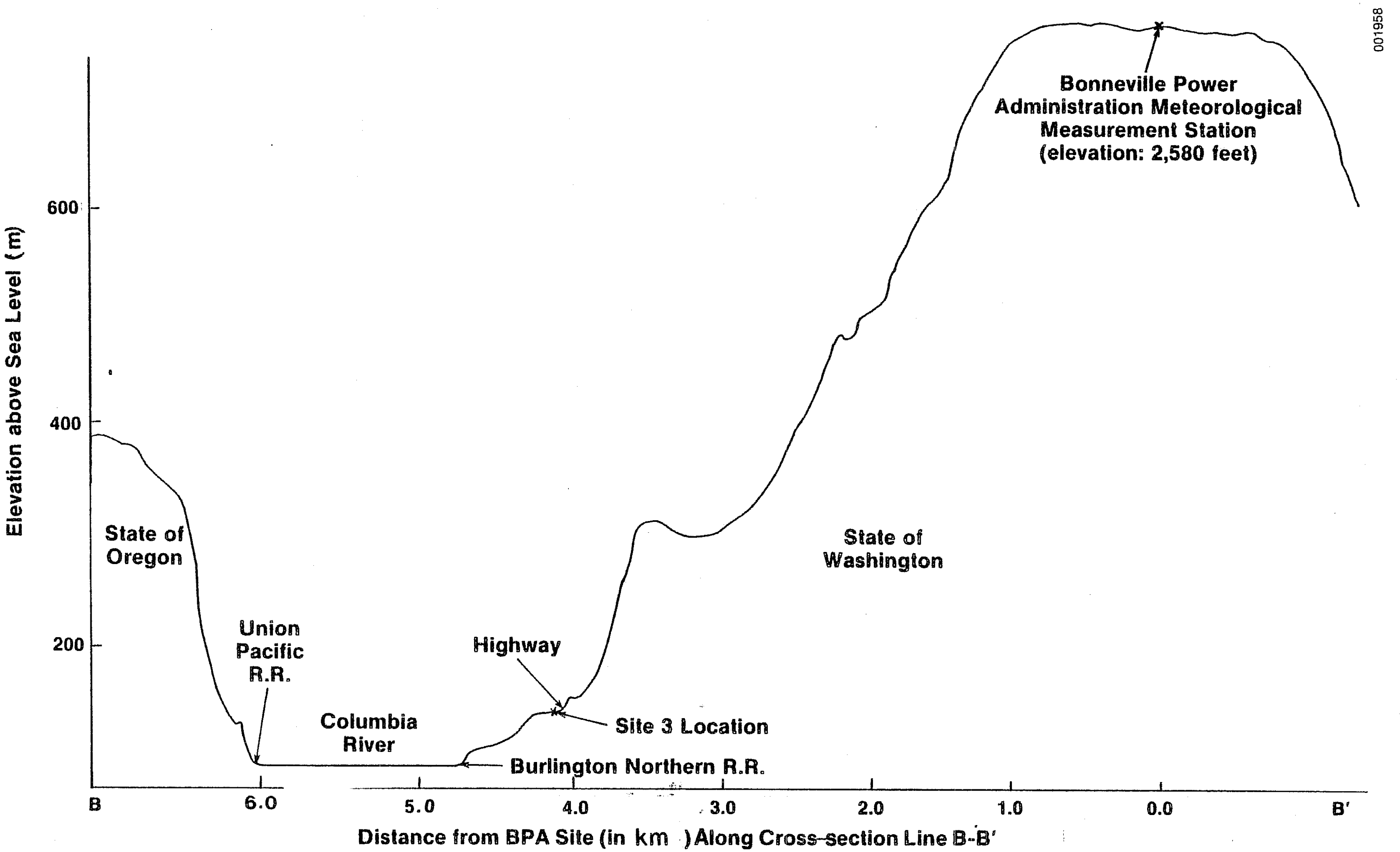

Figure 2-4. Topographic Cross Section B-B'

SECTION 3.0

INSTRUMENTATION

The three measurement sites were monitored over a three-day period, but, due to personnel and equipment limitations, not all sites could be monitored simultaneously. Site #1 (BPA met tower) was monitored during the entire period. Sites #2 and #3 were monitored 8 to 10 hours each as shown in Table 3-1.

Table 3-1. Noise Measurement Log

Location	Date	Period of Run (hours)
Site 1	6/17/80	1900-2050
		2100-2330
		2348-0151
	6/18/80	0212-0422
		0436-0640
		1155-1934
	6/19/80	1945-0617
		0838-1710
	6/20/80	1829-0300
Site 2	6/18/80	2122-2353
	6/19/80	0002-0215
		0225-0425
		0442-0654
Site 3	6/19/80	2020-2235
	6/20/80	2250-0039
		0053-0310
		0347-0554
		0628-0847

3.1 EQUIPMENT

The instrumentation used for this survey consisted of standard acoustic survey equipment and specialized low-frequency microphone systems. Most of the equipment was owned and maintained by SERI. However, some equipment was borrowed from the Region 10 EPA office, and we rented one GenRad 1945 Community Noise Analyzer. The equipment and its placement at each site are described below. The actual recorder and microphone configuration sheets are shown in Appendix C.

3.1.1 Site #1 (BPA met tower)

The following equipment was used to monitor and record the acoustic environment at Site #1 from 1900 hours on 17 June 1980 until 0300 hours on 20 June 1980:

- B&K Model 2631 Microphone Carrier System with Type 4145 Sealed Microphone
- B&K Model 2209 Precision Sound Level Meter (SLM) with Type 4145 Microphone
- B&K Model 8306 High Sensitivity Accelerometers (2 units)
- RACAL Model 7DS Magnetic Tape Recorder (used 17-18 June 1980)
- RACAL Model 4DS Magnetic Tape Recorder (used 18-20 June 1980)
- GenRad Model 1945 Community Noise Analyzer (CNA) with 1560-P42 Preamp and Type 1971/9601 Microphone
- GenRad Model 1981-B Precision SLM with 1962-9601 Microphone.

Figure 3-1 shows the locations of the equipment with respect to the construction, the trailer, and the chain link fence surrounding the met tower.

All microphones were elevated 1.2 m by tripods, allowing a minimum clearance of 75 cm above vegetation and rocks. The accelerometers were placed at the bottom of a 4-m deep pit used in the erection of the turbine tower. The accelerometer frame was weighted down on rock at the bottom of the pit in a position to allow vertical and horizontal axis vibration measurements to be made.

The RACAL 7-channel recorder was used to record acoustic signals from the B&K 2631 Microphone System and the B&K 2209 SLM, as well as signals from the B&K Accelerometers on June 17 and 18. On June 18-20, only acoustic signals were recorded using the 4-channel RACAL recorder. A GenRad Model 1521 B Graphic Level Recorder was used at all sites to make periodic strip chart recordings.

The recorders and the GenRad 1981-B SLM were placed inside the temperature controlled BPA trailer. The B&K 2209 SLM, the GenRad 1945 CNA, the B&K 2631 Carrier System, and accelerometer amplification system were placed outside.

3.1.2 Site #2

The following equipment was used on June 18-19 to monitor and record the acoustic environment at Site #2, a wheat field 7.2 km southeast of Site #1:

- B&K Model 2631 Microphone Carrier System with Type 4145 Sealed Microphone
- B&K Model 2209 Precision SLM with Type 4145 Microphone
- RACAL Model 7DS Magnetic Tape Recorder
- GenRad Model 1945 CNA with 1560-P42 Preamp and Type 1971-9601 Microphone
- GenRad Model 1981-B Precision SLM with Type 1962-9601 Microphone.

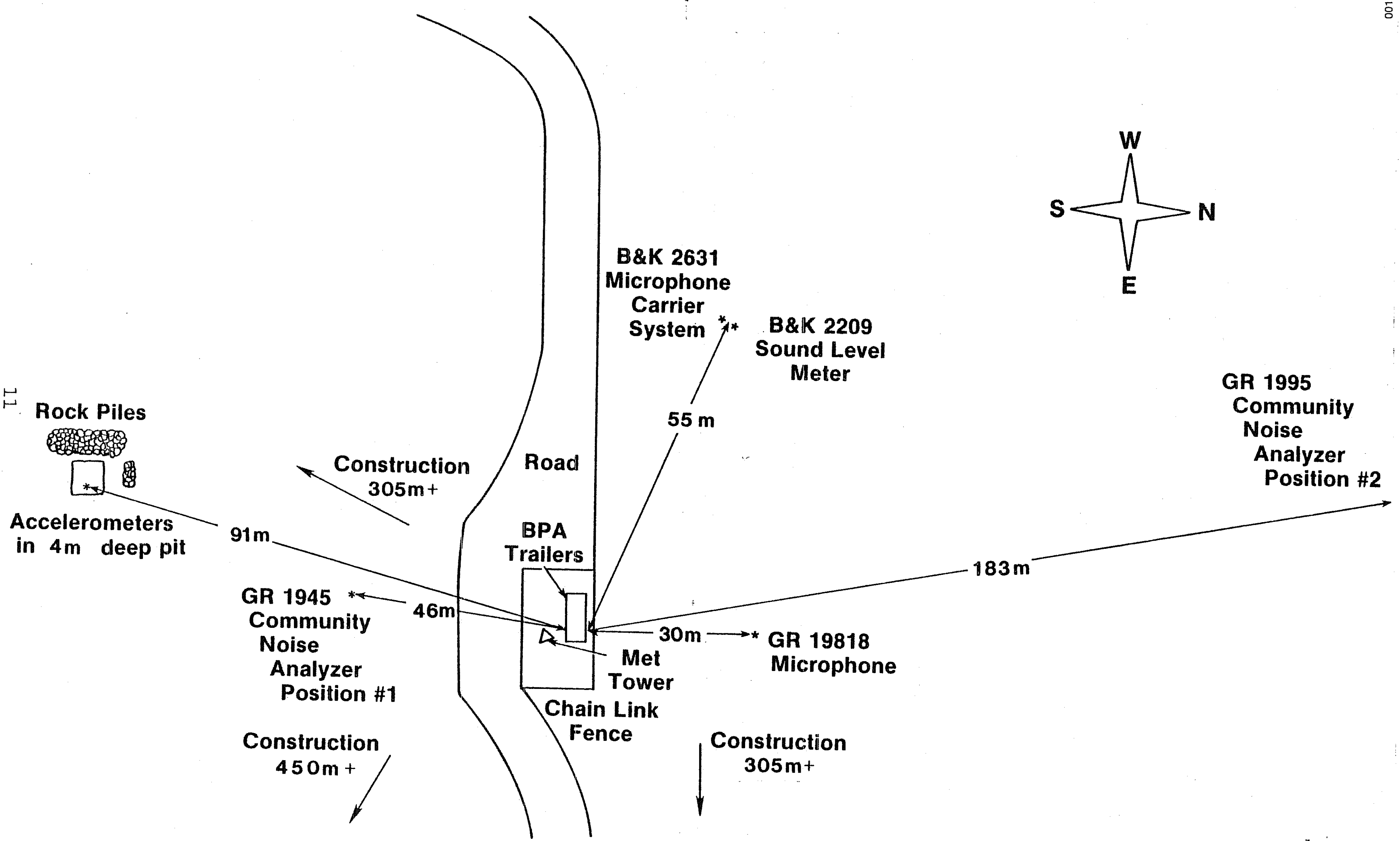

Figure 3-1. Site #1 Microphone Layout

Figure 3-2 shows the locations of the microphones with respect to various buildings and noise sources. All microphones were elevated 1.2 m, allowing a sufficient height above the 0.45-m high green wheat. The nearest unnatural reflecting object was a 5-m tall combine located 27 m from the microphones.

The B&K 2209 SLM and the B&K 2631 Carrier System were located 1.5 m apart on a hilltop, which was 9 m higher and 60 m northeast of the survey support vehicle. The GenRad 1945 and the GenRad 1981-B microphones were located 30 m east of the van in a gulch between two 15-m high hills. The RACAL 7DS Recorder and the GenRad 1981-B SLM were located inside the van.

3.1.3 Site #3

The following equipment was used on June 19-20 to monitor and record the acoustic environment at Site #3, 4 km SW of Site #1:

- B&K Model 2631 Microphone Carrier System with Type 4145 Sealed Microphone
- B&K Model 2209 Precision SLM with Type 4145 Microphone
- RACAL Model 7DS Magnetic Tape Recorder
- GenRad Model 1945 CNA with 1560-P42 Preamp and Type 1971-9601 Microphone
- GenRad Model 1981-B Precision SLM with Type 1962-9601 Microphone.

Figure 3-3 shows the locations of the microphones with respect to surrounding buildings and noise sources. As before, the microphones were set on 1.2-m tripods, raising them at least 1 m above vegetation. The microphones were located at least 24 m from any tall objects. As at the other sites, the RACAL 7DS recorder and the GenRad 1981-B SLM were located inside the van.

3.2 CALIBRATION OF INSTRUMENTS

All instruments, except those noted below, were calibrated to National Bureau of Standards traceability by B&K, GenRad, or SERI Calibration Laboratories within six months prior to the testing period. The following equipment was borrowed from the EPA Region 10 Office. That equipment was found to be within manufacturers' specifications when tested in the SERI laboratory.

- B&K 2209 SLM with 4145 Microphone
- GenRad 1521-B Graphic Level Recorder (with 40 dB Potentiometer belonging to Engineering Dynamics, Inc.)
- GenRad 1981-B SLM
- B&K 4230 Sound Level Calibrator (SLC)

In addition, a rented GenRad 1945 CNA was also within manufacturers' specifications when checked.

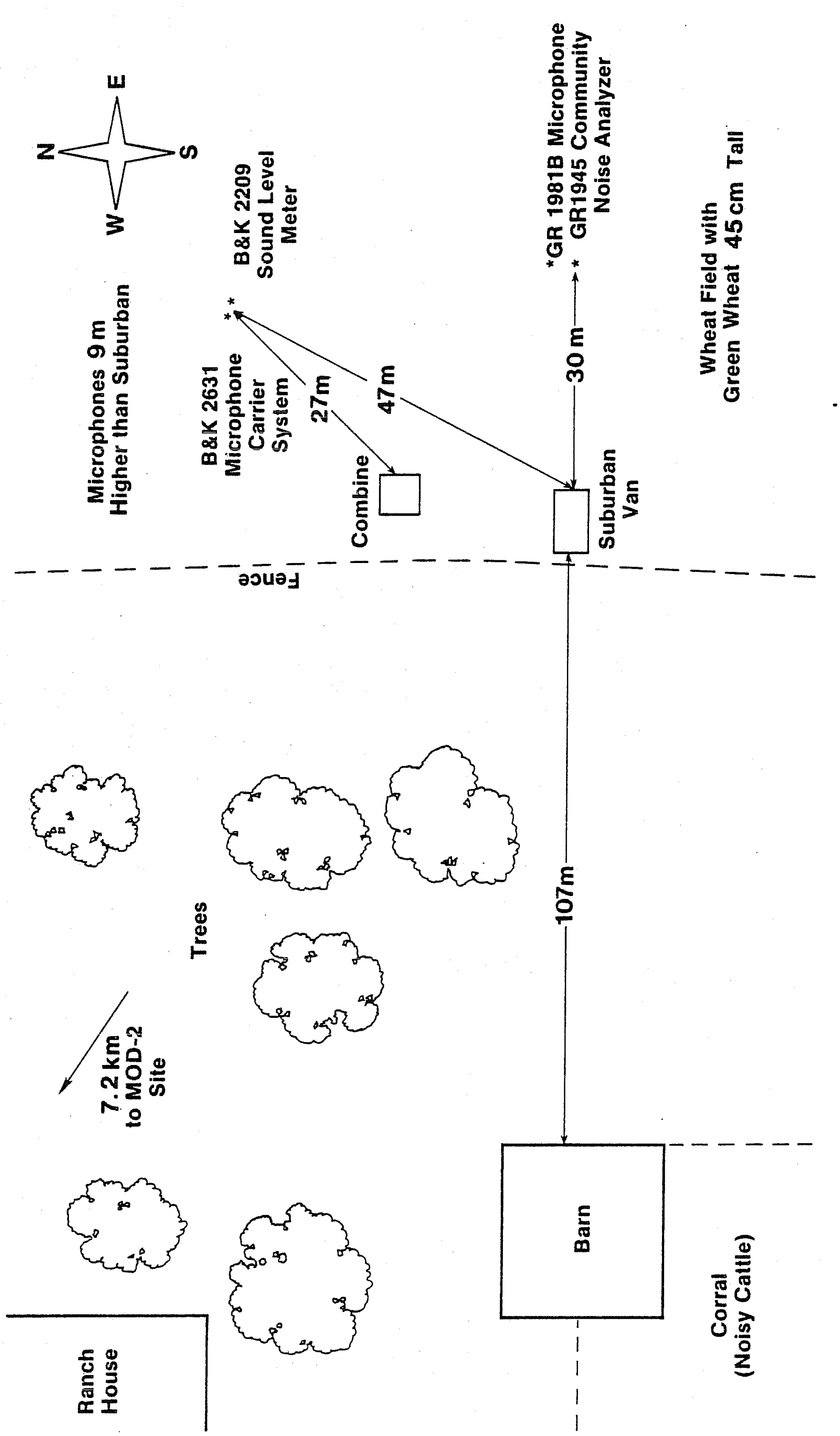

Figure 3-2. Site #2 Microphone Layout

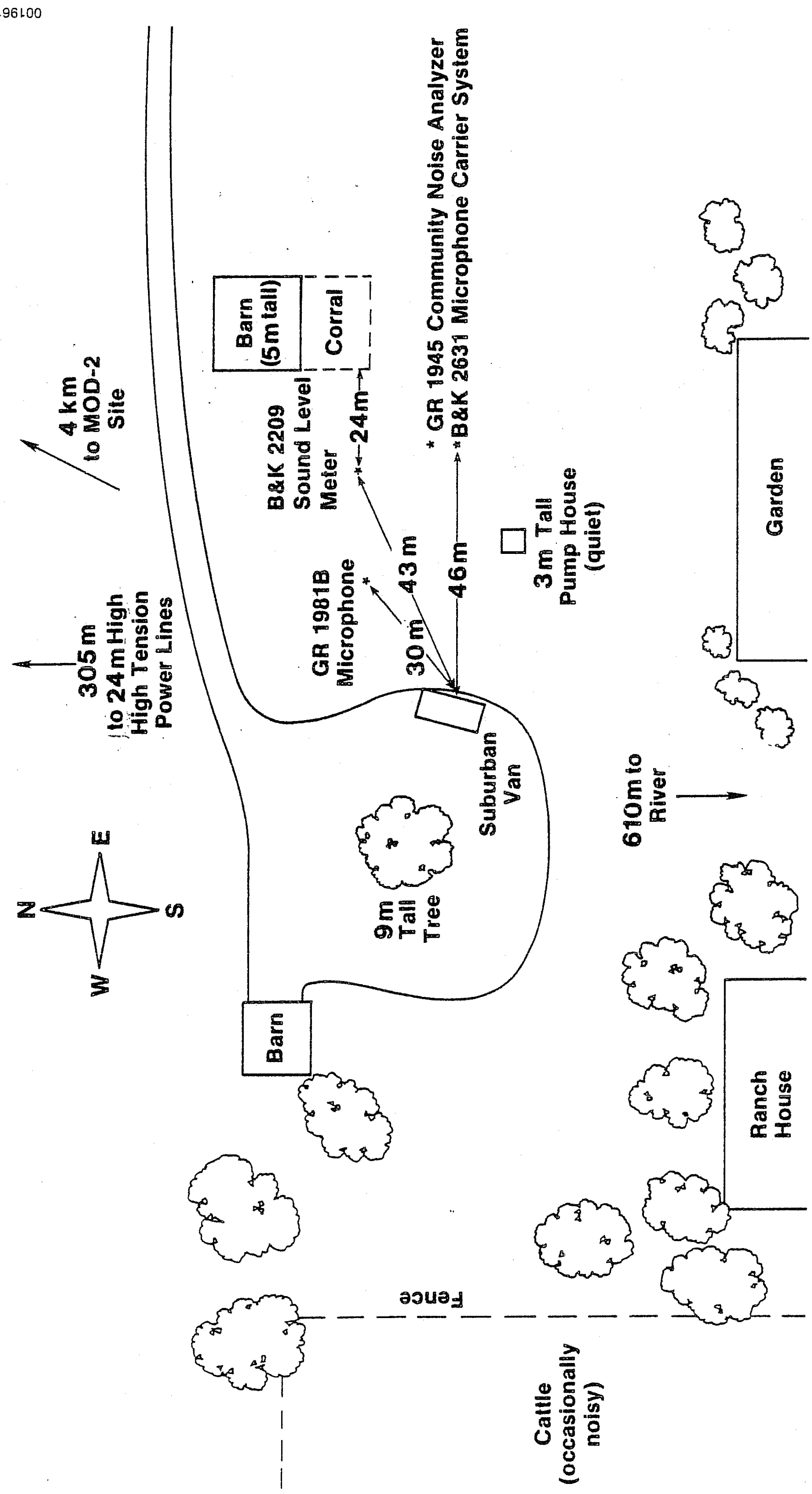

Figure 3-3. Site #3 Microphone Layout

SECTION 4.0

RESULTS AND TECHNICAL DISCUSSION

The acoustic data collected at and around the MOD-2 sites were analyzed using the Community Noise Analyzer (CNA) probabilistic analysis and spectrum analysis of both acoustic and infrasound levels. The data from the B&K 8306 accelerometers are not presented. This instrumentation was not appropriate for outside use and yielded unreliable and unusable results. In the following subsections, the acoustic data analysis methods are presented and discussed.

4.1 COMMUNITY NOISE ANALYZER

The GenRad 1945 Community Noise Analyzer samples existing noise levels during a predetermined time interval and displays the data in terms of exceedance levels. For example, a value designated "L_x" is the sound pressure level (SPL) in dB(A) re 20 μPa exceeded "x" percent of the sampling time interval. The CNA can be programmed to collect data for designated time intervals ranging from 1/2 hour to 24 hours, and may be set to operate during 1, 2, or 3 consecutive time intervals. Shorter measurement intervals provide greater resolution of the variable acoustic environment. The data then can be averaged over a longer period of time by combining a series of short measurement intervals.

At Site #1 (BPA met tower) the CNA measured noise levels for a total period of 12 hours between 0300 and 0700 hours on 18 June 1980 and 0830 and 1630 hours on 19 June 1980. At Sites #2 and #3, the CNA was in use only at night, from 2200 to 0700 hours on June 18-19 at Site #2, and 2000 to 0700 hours on June 19-20 at Site #3. The results from all three sites are summarized in Table 4-1. The complete CNA field data sheets are shown in Appendix D.

The SPL at each L_x can be plotted on probability paper to determine a probability distribution of the sound levels, showing graphically the probability of a given SPL being exceeded at a given site. A probability plot for the met tower site (Site #1) is shown in Fig. 4-1, comparing average day and night values. As can be seen from this graph, Site #1 is typical of undeveloped, rural areas, where the nighttime levels are almost identical with the daytime levels. At all three sites the recorded levels are dominated by isolated events.

The day-night sound level (designated L_{dn}) was not calculated for any of the sites; however, sufficient acoustic data were recorded at Site #1 to determine the value of this descriptor if it is needed at a later time. The $L_{10,50,90}$ and L_{eq} values can be considered representative of the site acoustic levels. All three sites can be described as quiet for the time periods in which the measurements were taken.

4.2 AUDIBLE SOUND ANALYSIS

Analysis of the audible range of the spectrum shows that, as expected, the

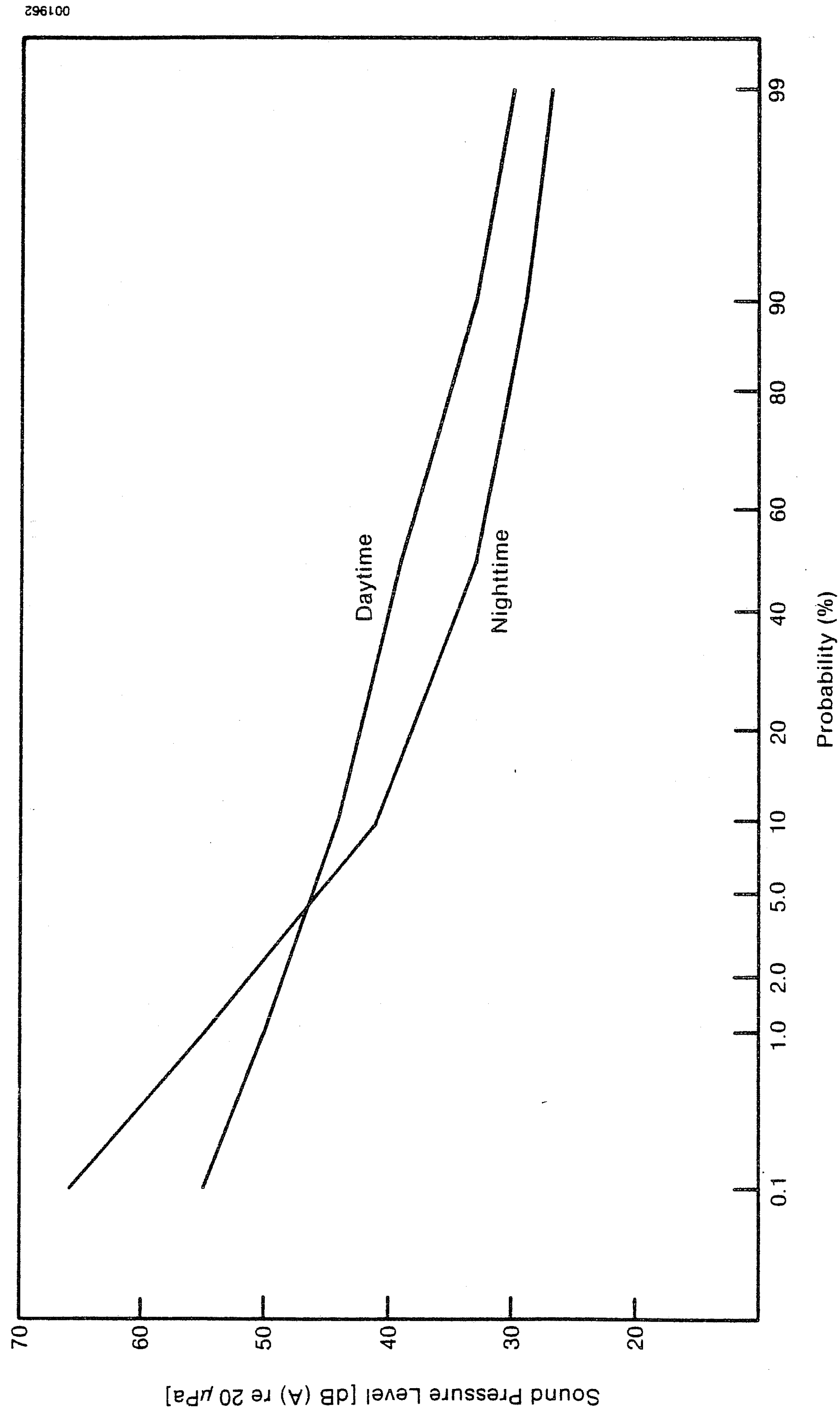

Figure 4-1. CNA Probability Plot

Table 4-1. Probability Analysis Results

Site #1 (BPA met tower)

Level	Daytime			Average	Nighttime		Average
0.1	49	56	61	55	59	73	66
1.0	46	50	55	50	52	58	55
10	42	44	47	44	41	41	41
50	36	38	42	39	33	33	33
90	32	33	35	33	29	29	29
99	30	30	31	30	27	27	27
Duration (h)	1	2	1	--	4	4	--

Site #2 and #3 (Nighttime)

Level	Site #2			Average	Site #3			Average
0.1	74	53	60	62	65	67	80	74
1.0	68	50	55	58	57	58	79	69
10	57	39	50	49	48	46	73	61
50	42	32	45	40	39	39	40	39
90	33	28	39	33	35	36	36	36
99	28	26	34	29	31	35	34	34
Duration (h)	3	3	3	--	2	3	6	--

audible sounds recorded at Site #1 during the daytime hours (0700 to 2200 hours) are higher than those recorded during the nighttime hours by 8 to 12 dB. While no daytime recordings were made at Sites #2 and #3, we presume that a similar situation exists there. Of the three sites, Site #1 is the quietest by up to 10 dB. This would be expected since the site is more isolated and lacks the obvious nocturnal noise sources present at the other sites.

4.2.1 Site #1

Figure 4-2 shows the root sum squared (RSS) spectrum of daytime levels recorded at Site #1 in the low audible range (DC to 1000 Hz, effective bandwidth 1.25 Hz). The broad peak around 200 Hz is probably due to aeolian (vortex) shedding from the microphone support tripod or other site-specific sources. There is some evidence of 60-Hz contamination, probably due to a ground loop in the recording system.

Figure 4-3 shows the nighttime levels from the met tower site over the DC to 2000 Hz range (effective bandwidth 2.5 Hz). Unfortunately, Figs. 4-2 and 4-3 are not directly comparable because of the differences in the frequency scale. However, by comparing specific points, it can be seen that the nighttime levels are 8 to 10 dB lower than those during the day. Once again the spectral peaks in Fig. 4-3 are most likely due to aeolian shedding and 60-Hz contamination.

The full audible spectrum (DC to 20 kHz, effective bandwidth 25 Hz) is shown in Fig. 4-4 for nighttime only. The high frequency peaks in this spectrum are most likely the result of normal nighttime sounds (crickets, etc.) and not shedding or 60-Hz contamination.

4.2.2 Sites #2 and #3

Figures 4-5 and 4-6 show the nighttime levels (DC to 2000 Hz, effective bandwidth 2.5 Hz) for Sites #2 and #3, respectively. The predominant sounds at both sites were from penned cattle. Site #3 was slightly more noisy due to the proximity of the railroad tracks and a busy highway. This is reflected in a 10-dB difference between the spectra below 1000 Hz. The noise floor of the recorder was near 20 dB for the two recording sessions.

Figures 4-7 and 4-8 show the full nighttime audible spectrum (DC to 20 kHz, effective bandwidth 25 Hz) for Sites #2 and #3, respectively. While recording at Site #2, the noise floor of that channel of the recorder was evidently set at 20 dB, while at Site #3 it was set closer to 10 dB. It is this difference in noise floors that causes the vast difference in the shape of the two spectra. The spikes in Fig. 4-7 are the only significant part above approximately 4000 Hz. Figure 4-8 shows a more typical spectrum extending down to 10 dB. The very broad peak around 4000 Hz is from an unknown source, possibly related to the pumphouse near the recording site.

4.3 INFRASOUND ANALYSIS

Figures 4-9 and 4-10 show the daytime and nighttime infrasound (DC to 20 Hz, effective bandwidth 0.025 Hz) levels recorded at Site #1. Once again the daytime levels are higher than during the night, in this case by 5 to 15 dB. The shapes of the spectra are very similar, indicating only that the level drops at night, leaving the relative spectral distribution of the infrasound unchanged.

For comparison purposes the nighttime infrasound levels from Sites #2 and #3

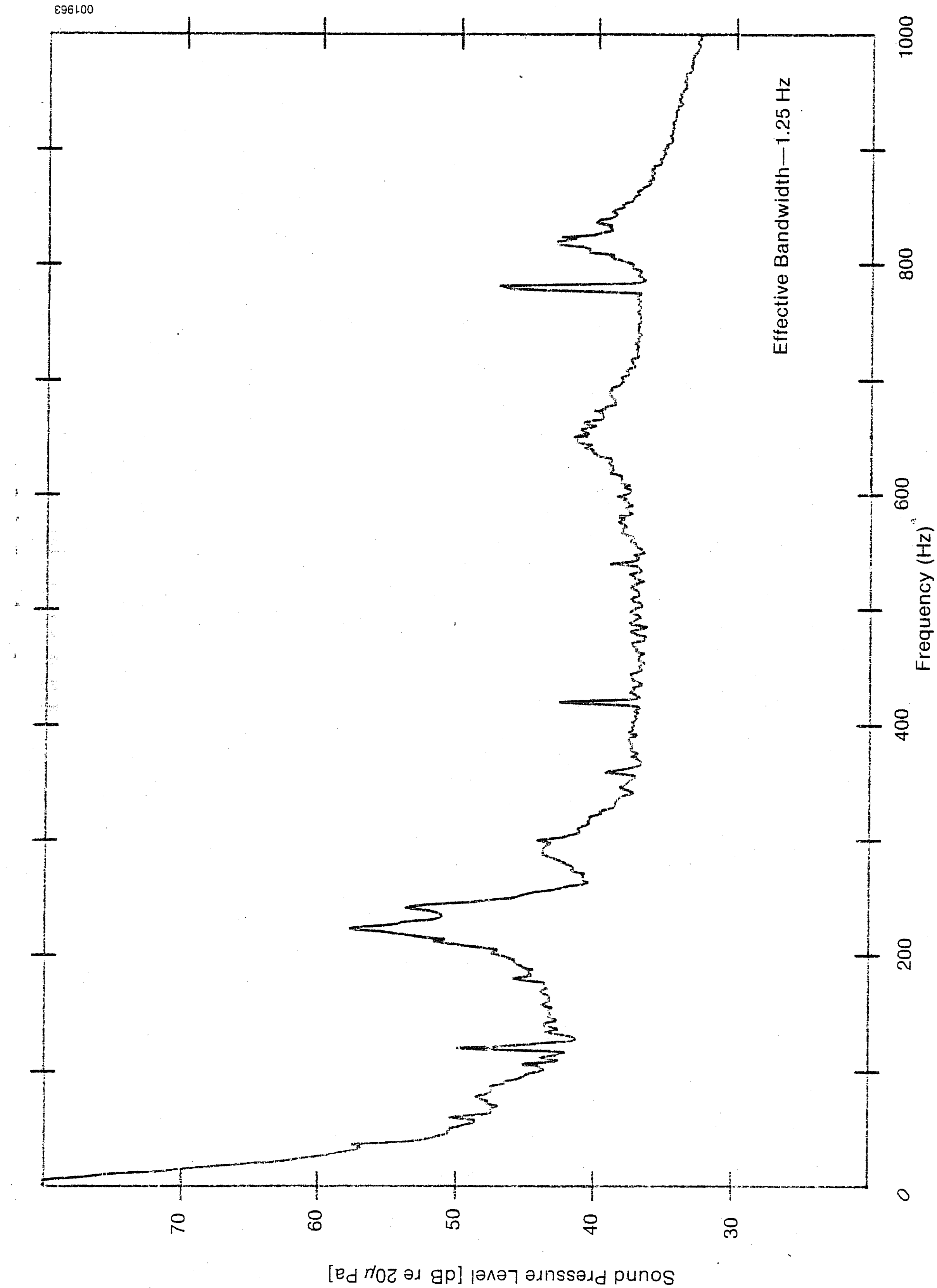

Figure 4-2. Site #1 Limited Audible Spectrum, Daytime

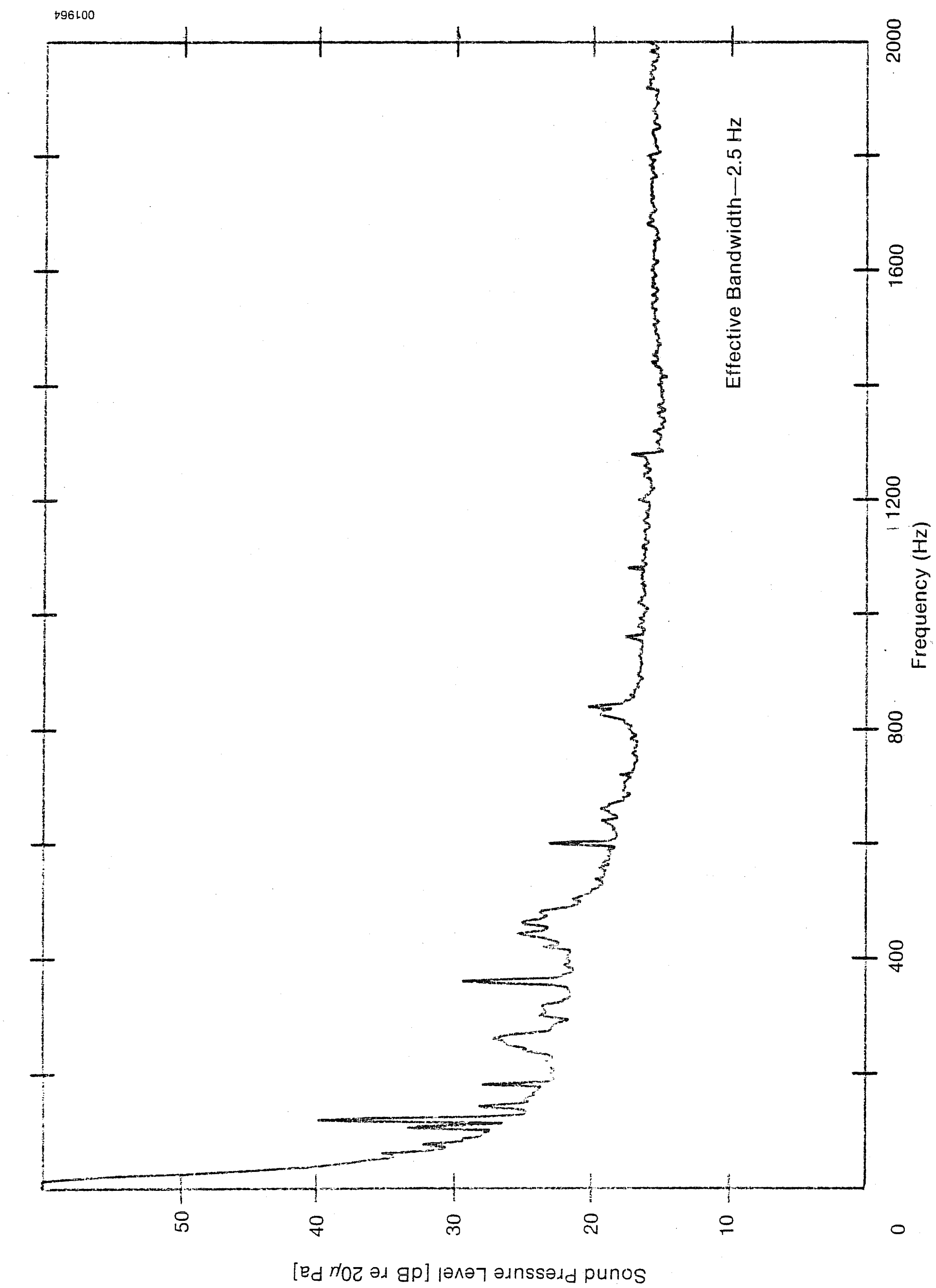

Figure 4-3. Site #1 Limited Audible Spectrum, Nighttime

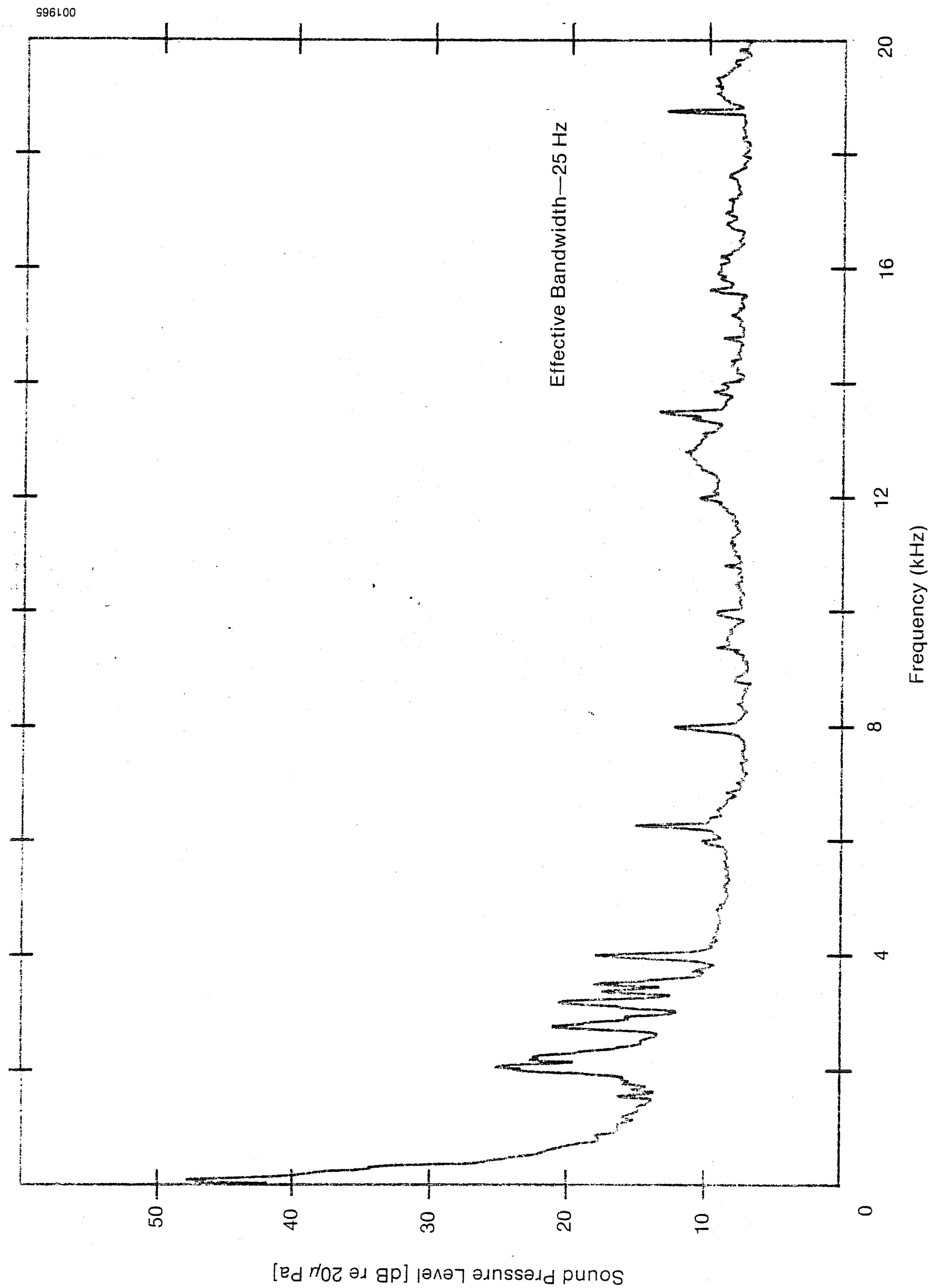

Figure 4-4. Site #1 Entire Audible Spectrum, Nighttime

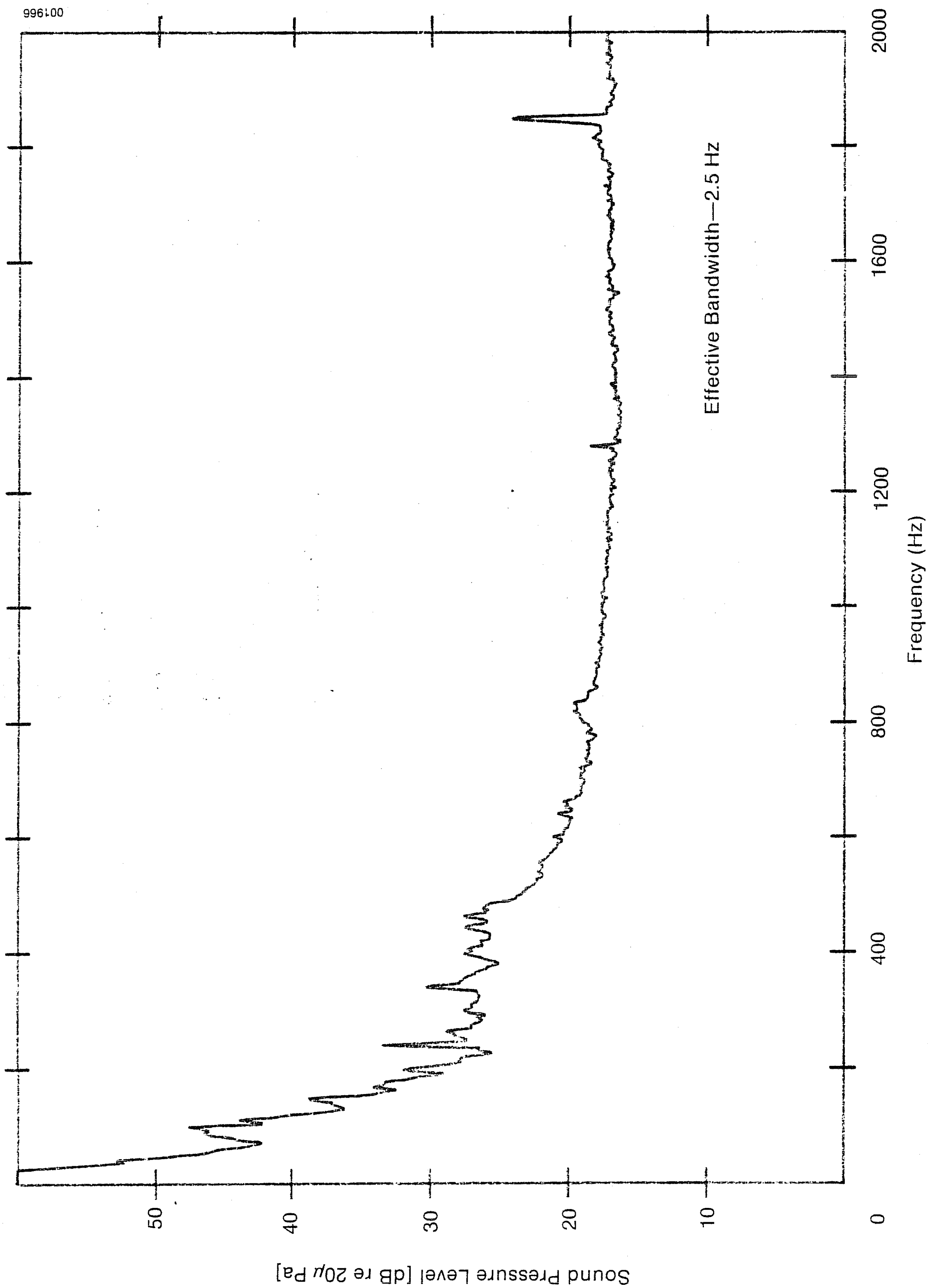

Figure 4-5. Site #2 Limited Audible Spectrum, Nighttime

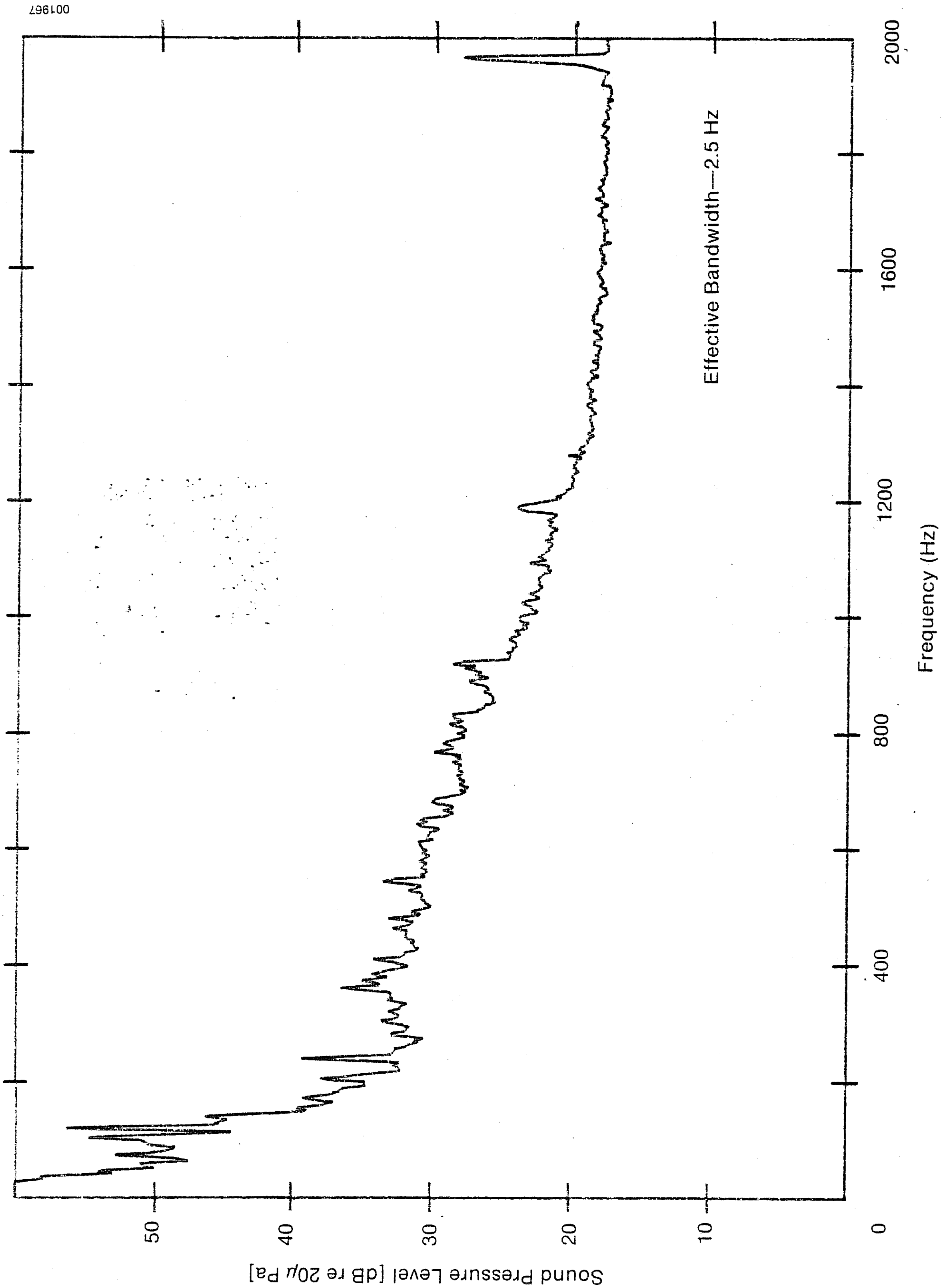

Figure 4-6. Site #3 Limited Audible Spectrum, Nighttime

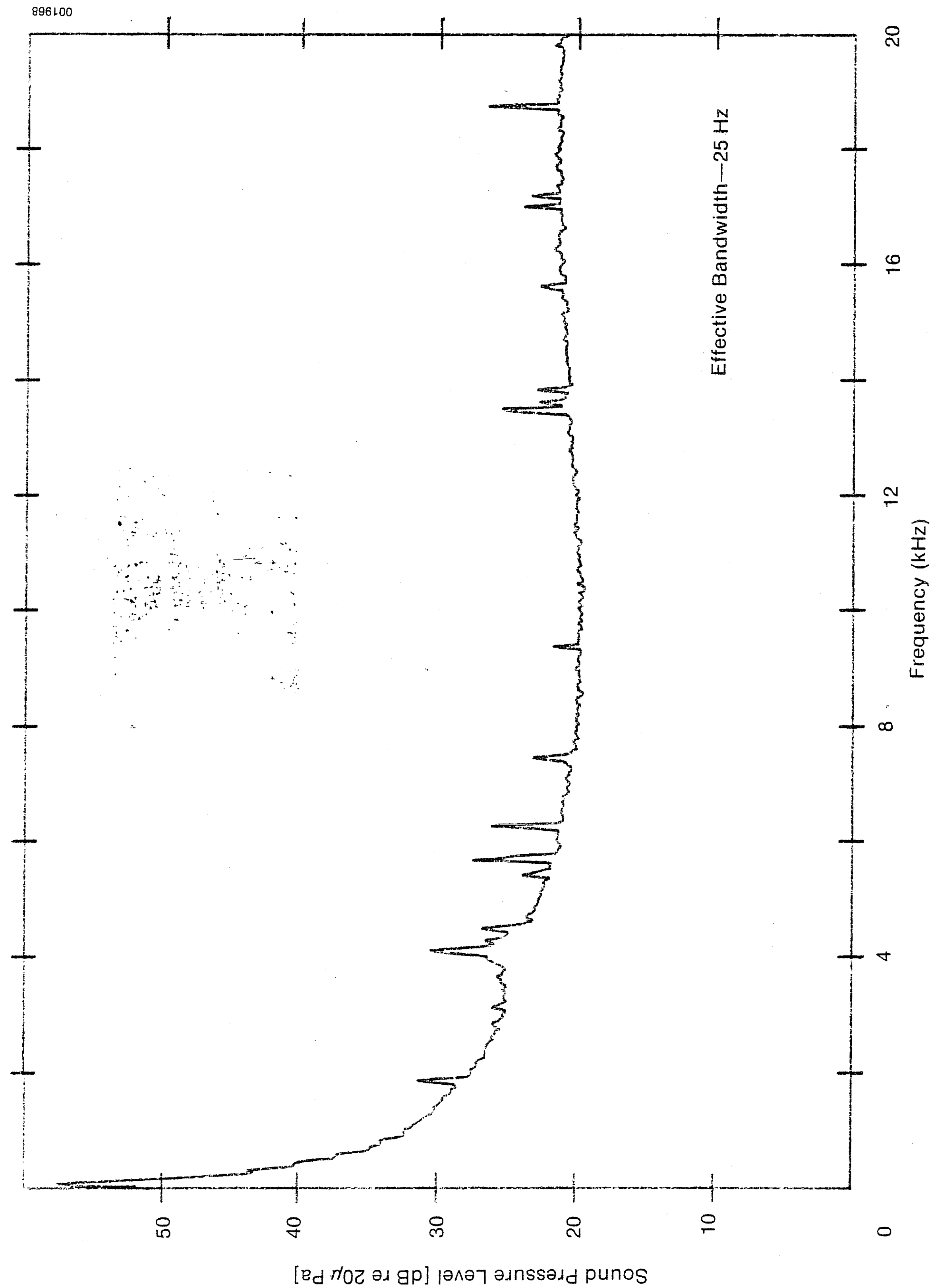

Figure 4-7. Site #2 Entire Audible Spectrum, Nighttime

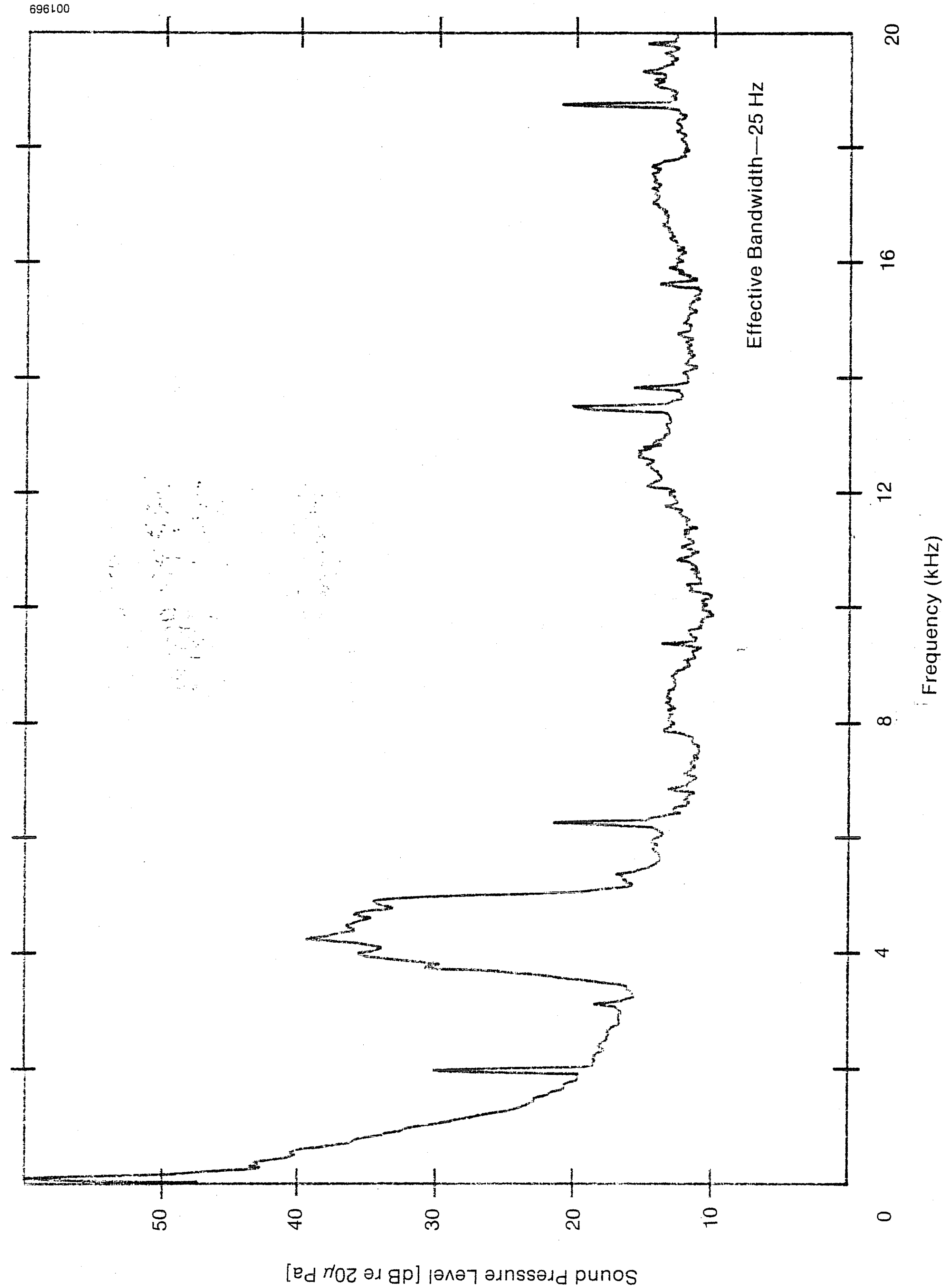

Figure 4-8. Site #3 Entire Audible Spectrum, Nighttime

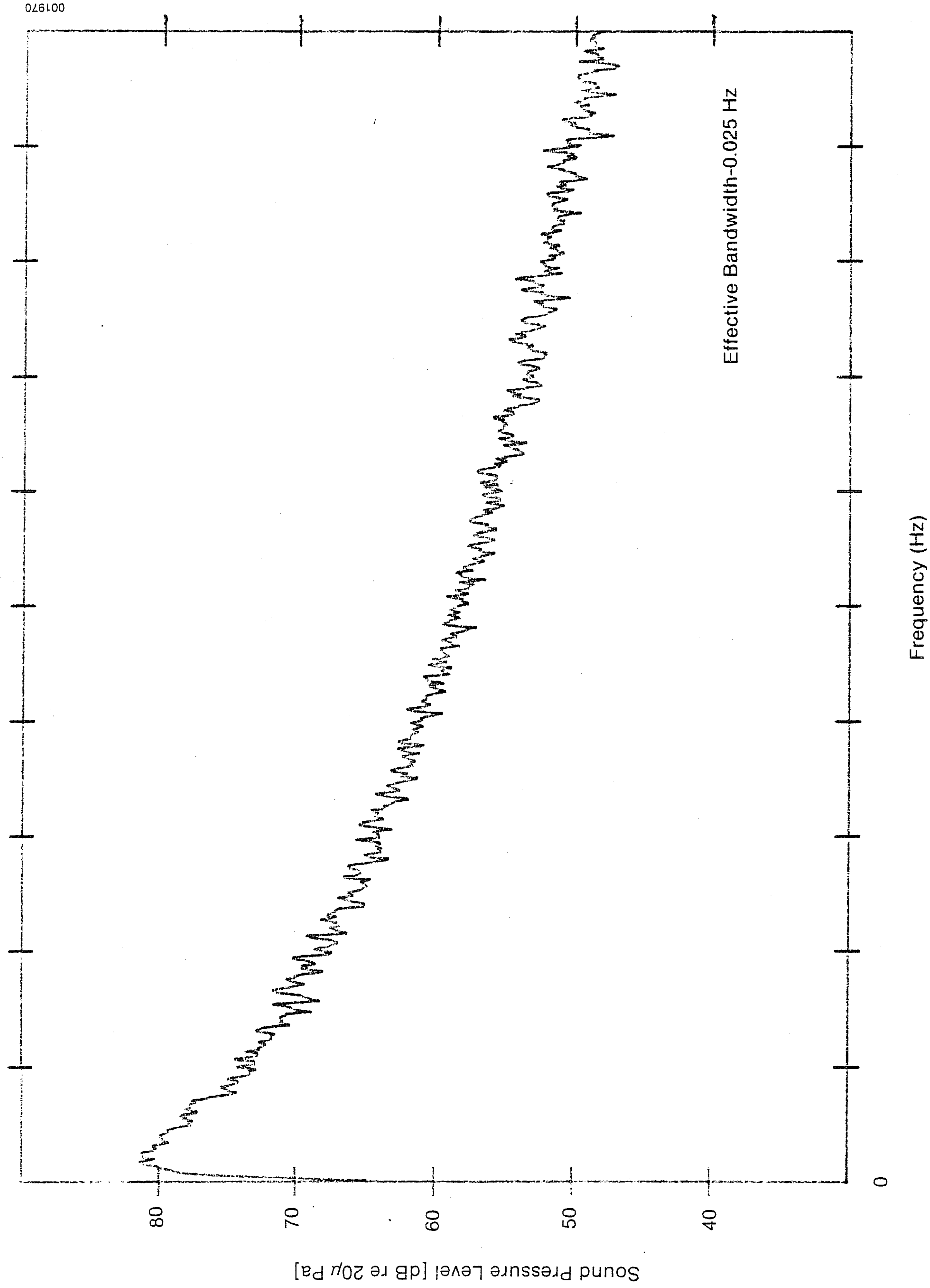

Figure 4-9. Site #1 Infrasound Spectrum, Daytime

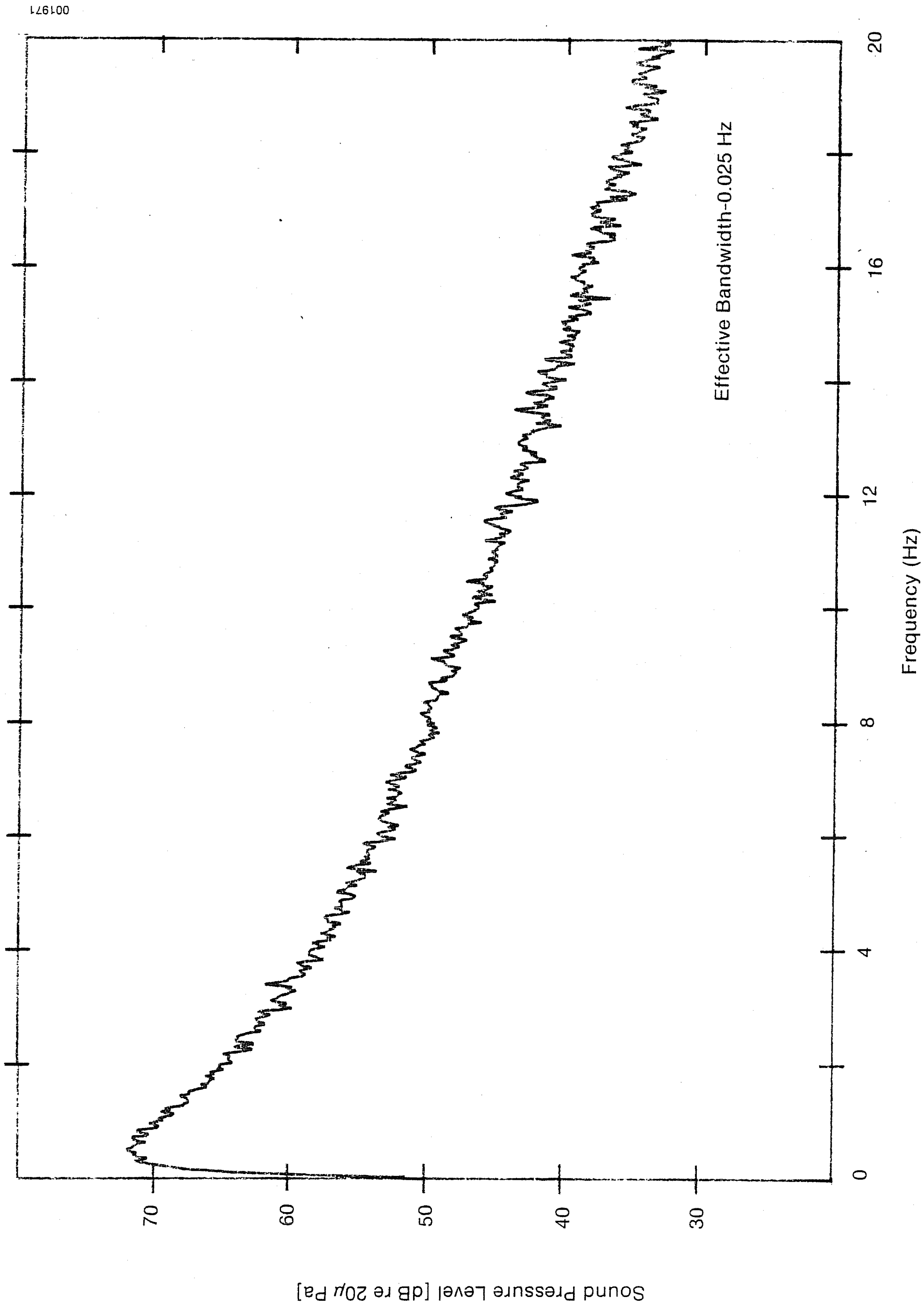

Figure 4-10. Site #1 Infrasound Spectrum, Nighttime

are shown in Figs. 4-11 and 4-12, respectively. The levels recorded at Site #2 are identical with those recorded at Site #1, while those found at Site #3 are roughly 10 dB lower than those at Sites #1 and #2.

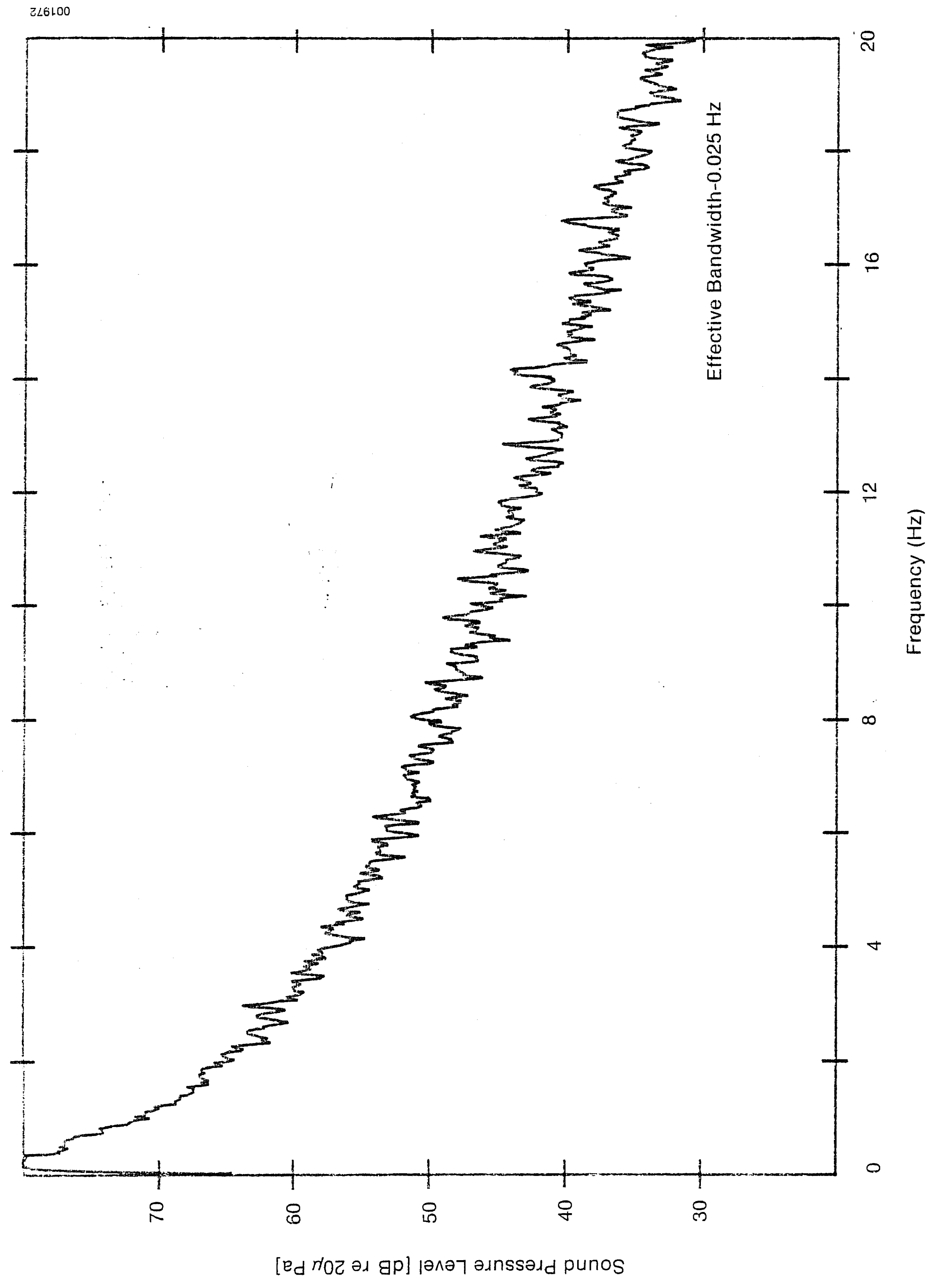

Figure 4-11. Site #2 Infrasound Spectrum, Nighttime

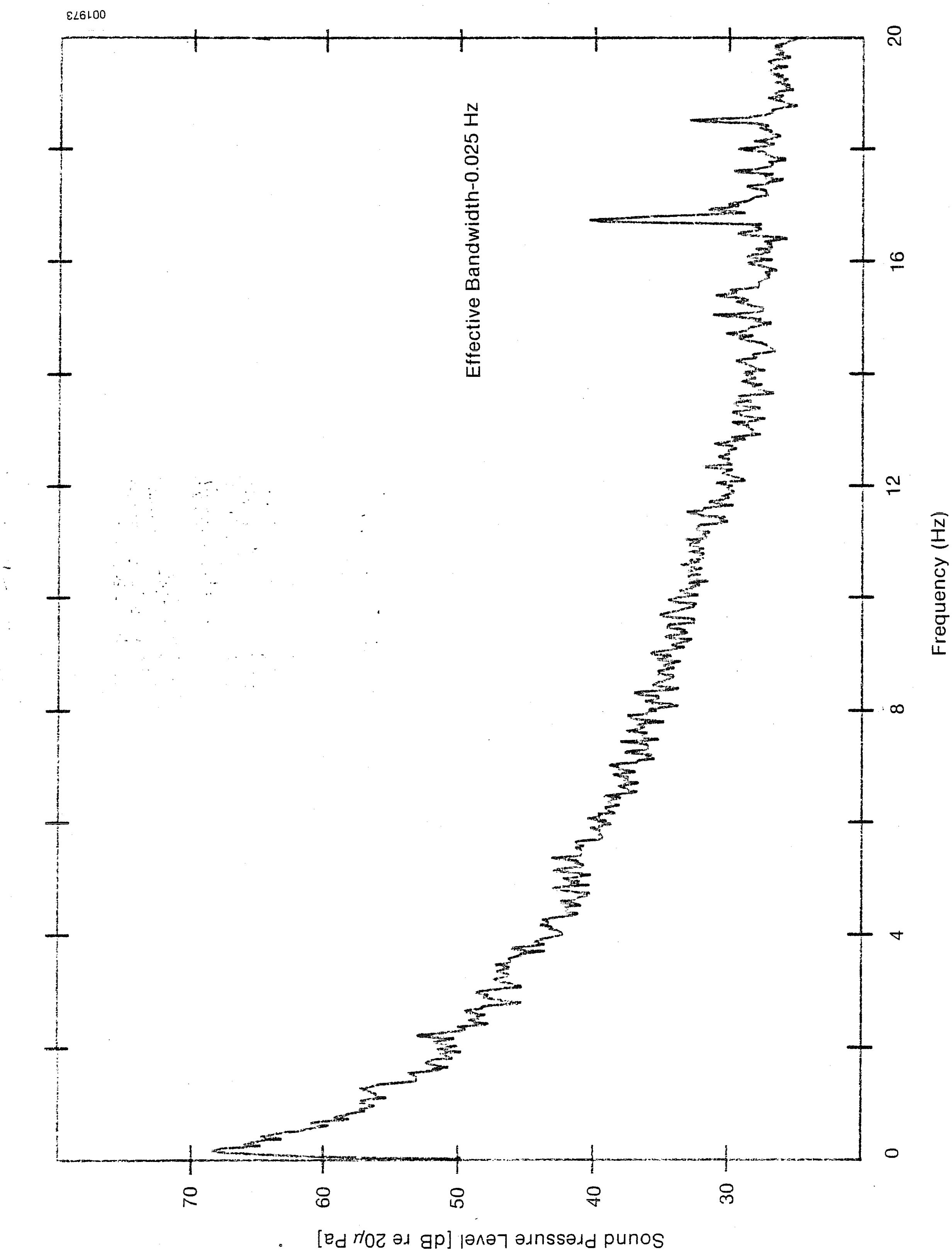

Figure 4-12. Site #3 Infrasound Spectrum, Nighttime

SECTION 5.0

CONCLUSIONS AND SUGGESTIONS

5.1 CONCLUSIONS

This publication is intended to complement future measurements of the MOD-2 wind turbines by providing documentation of acoustic background levels in the Goodnoe Hills area. The survey meets the requirements of the EPA for baseline noise surveys.

Our findings indicate that the Goodnoe Hills site is acoustically typical of little-developed rural areas. There are no major sources of man-made noise at the wind turbine site, other than those associated with the wind turbine construction. The surrounding area is also quiet, with the major sound sources being animals, cars on the few highways in the area, and trains passing on the nearby tracks.

The data from the B&K 8306 sensitivity accelerometers were not presented because the instrumentation was not appropriate for the wide temperature fluctuations encountered in use outdoors, and therefore yielded unreliable results. Future surveys requiring short-term seismological data will be furnished with instrumentation properly designed for such purposes.

5.2 SUGGESTIONS

Besides providing useful acoustic baseline data, this survey demonstrated that further improvements in measurement techniques could be made. Toward that end we make the following suggestions to encourage discussion and the development of better methods and instrumentation:

- Future survey sites should include all quadrant areas surrounding the wind turbine site. The choice of sites should consider year-round accessibility.
- Surveys should be conducted at different times during the year, to reflect the seasonal variations of sound levels due to changes in the state of the local atmosphere, i.e., presence or absence of temperature inversions, etc.
- The sound level instrumentation for use at far-field sites should be completely portable and protected from the elements for optimum performance at both attended and unattended measurement locations. Ideally, the instrumentation should be able to operate from battery packs to allow maximum flexibility in site selection.
- For the future assessment of microseismic effects induced by the wind turbines, proper seismometers should be employed that have the following characteristics: a frequency response range of at least 0.1 to 100 Hz, high sensitivity, a broad operating temperature range, and a small bore hole configuration.

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SECTION 6.0

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APPENDIX A

ACOUSTICAL TERMS

A.1 DEFINITIONS

The following terms may be needed in preparing environmental measurements concerned with noise. The following descriptions are extracted from EPA (1974). The terms are listed generally in order of frequency of use. A time period used as an abbreviation or as a subscript for the symbol for a sound level signifies an A-weighted average over that time period. Abbreviations and symbols are listed in Table A-1.

Sound Level. The quantity in decibels measured by an instrument satisfying requirements of American National Standard Specification for Sound Level Meters (S1.4-1971). Fast time-averaging and A-frequency weighting are understood, unless others are specified. The sound level meter with the A-weighting is progressively less sensitive to sounds below 1000 Hz, as the ear is. With fast-time averaging, the meter responds particularly to recent sounds almost as quickly as the ear does in judging the loudness of a sound.

Noise Level. Same as sound level, for sound in air. Some people use "noise" only for undesirable sound; however, a sound level meter does not measure people's desires. Hence, there is less likelihood of misunderstanding if what is measured is called sound level rather than noise level.

Decibel. A unit measure of sound level referenced to 20 micropascals (μPa). Other quantitites may be similarly expressed as logarithms of ratios with particular reference levels.

Maximum Sound Level. The greatest sound level during a designated time interval or event. More specifically, it is the greatest A-weighted sound level of the event.

Peak Sound Level. The greatest instantaneous A-weighted sound level, during a designated time interval or event.

Impulse Sound Level. In decibels, the exponential-time-average sound level obtained with a squared-pressure time constant of 35 ms. The A-frequency weighting is understood.

Fast Sound Level. In decibels, the exponential-time-average sound level measured with the squared-pressure time constant of 125 ms. The A-frequency weighting is understood.

Table A-1. SOME ACOUSTICAL TERMS, ABBREVIATIONS, AND SYMBOLS FOR ENVIRONMENTAL MEASUREMENTS

Term	Abbreviation	Symbol
Sound level (fast A-weighted)	A	L_A,L
Noise level (sound level)	A	L_A,L
Decibel	DB	dB
Maximum sound level	MXL	L_{max}
Peak sound level	PKL	L_{Apk}
Impulse sound level	ISL	L_{AI}
Fast sound level	FA	L_{AF}
Slow sound level	SA	L_{AS}
Sound level exceeded x-percent of time	LX	L_x
Average sound level, over time T	AVL	L_T
Equivalent continuous sound level over time T	EQL	L_{eqT}
Hourly average sound level	1HL	L_h
8-hour average sound level	8HL	L_{8h}
Day (0700-2200) average sound level	DL	L_d
Night (0000-0700 and 2200-2400) average sound level	NL	L_n
Day-night average sound level	DNL	L_{dn}
Peak sound pressure, in stated band	PKSP	P_{pk}
Peak sound pressure level, in stated band	PKSPL	L_{pk}
Sound pressure, in stated band	SP	p
Sound pressure level, in stated band	SPL	L_p
(Vibratory) acceleration, in stated band	VA	a
(Vibratory) acceleration level, in stated band	VAL	L_a

Sound Level Exceeded x-Percent of Time. That sound level equaled or exceeded by a fluctuating fast sound level x-percent of a stated time period. L_{10}, for example, is a sound level exceeded 10% of 24 hours.

Average Sound Level. A sound level typical of a given location in a stated time period. Technically, average sound level in decibels is the level of the mean-square A-weighted sound pressure during the stated time period, with reference to the square of the standard reference sound pressure of 20 μPa. Average sound level differs from sound level in that for average sound level, equal emphasis is given to all sounds within the stated averaging period. For sound level, an exponential time weighting puts much more emphasis on sounds that have just occurred than those which occurred earlier.

Equivalent Continuous Sound Level. Same as average sound level. The pertinent time period must be stated.

Hourly Average Sound Level. Average sound level, in decibels, over a one-hour time period, usually reckoned between integral hours. It may be identified by the beginning and ending times, or by the ending time only.

8-Hour Average Sound Level. Average sound level, in decibels, over an 8-hour period.

Day Average Sound Level. Average sound level over the 15-hour time period from 0700 to 2200 hours.

Night Average Sound Level. Average sound level, in decibels, over the split nine-hour period from 0000 to 0700 and from 2200 to 2400 hours.

Day-Night Average Sound Level. The 24-hour average sound level, in decibels, from midnight to midnight, obtained after addition of 10 decibels to sound levels in the night from 0000 to 0700 and from 2200 to 2400 hours.

Peak Sound Pressure. Greatest absolute instantaneous sound pressure in a stated frequency band, during a given time interval.

Peak Sound Pressure Level. In decibels, 20 times the common logarithm of the ratio of a greatest absolute instantaneous sound pressure to the reference sound pressure of 20 μPa (0.0002 microbar).

Sound Pressure. Root-mean-square of instantaneous sound pressures over a given time interval. The frequency bandwidth must be identified.

Sound Pressure Level. In decibels, twenty times the common logarithm of the ratio of a sound pressure to the reference sound pressure of 20 μPa. The frequency bandwidth must be identified.

(Vibratory) Acceleration. The rate of change of speed and direction of a vibration, in a specified direction. The frequency bandwidth must be identified.

(Vibratory) Acceleration Level. In decibels, 20 times the common logarithm of the ratio of a vibratory acceleration to the reference acceleration of 10 $\mu m/s^2$ (nearly one-millionth of the standard acceleration of free fall). The frequency bandwidth must be identified.

A.2 MATHEMATICAL FORMULATIONS

A.2.1 Average Sound Level (L_{eq} or L_T)

$$L_T = 10 \log_{10} \left[\frac{1}{T} \int_0^T 10^{L_A(t)/10} dt\right] , \qquad \text{(A-1)}$$

where T is the length of the time interval, in seconds, during which the average is taken; $L_A(t)$ is the time-varying value of the A-weighted sound level during the time interval T.

Note 1: Average sound level may be calculated from the sound exposure levels of individual events occurring within the time interval T:

$$L_T = 10 \log_{10} \left[\frac{1}{T} \sum_{i=1}^{n} 10^{L_{AEi}/10}\right] , \qquad \text{(A-2)}$$

where L_{AEi} is the sound exposure level of the i^{th} event, out of a total of n events in time interval T, expressed in seconds.

Note 2: When T is exactly one hour, L_T is referred to as an hourly average sound level.

A2.2 Day-Night Average Sound Level

The most common descriptor used to characterize the acoustic environment of a given site is the day-night sound level, designated L_{dn}.

$$L_{dn} = 10 \log_{10} \left[\frac{1}{86400} \left(\int_{0000}^{0700} 10^{(L_A(t) + 10)/10} dt + \int_{0700}^{2200} 10^{[L_A(t)/10]} dt + \int_{2200}^{2400} 10^{(L_A(t) + 10)/10} dt \right.\right. , \qquad \text{(A-3)}$$

where time t is in seconds, so the limits shown in hours and minutes are actually interpreted in seconds. It is often convenient to compute day-night average sound level from hourly average sound levels obtained during successive hours. The day-night sound level (L_{dn}) is defined as the equivalent A-weighted sound level during a 24-hour time period with a 10-dB weighting applied to the equivalent sound level during the nighttime hours of 2200 to 0700 hours. The L_{dn} may also be expressed by the equation:

$$L_{dn} = 10 \log_{10} \frac{1}{24}[15 \left(10^{L_d/10}\right) + 9\left(10^{(L_n + 10)/10}\right)] \text{ dB} , \qquad \text{(A-4)}$$

where

$L_d = L_{eq}$ for the daytime (0700–2200 hours)

$L_n = L_{eq}$ for the nighttime (2200–0700 hours).

The choice of 10 dB for the nighttime weighting was predicated on its extensive prior usage, together with an examination of the diurnal variation in environmental noise. This variation is best illustrated by comparing the difference between L_d and L_n as a function of L_{dn} over a range of environmental noise situations.

Data from 63 sets of measurements were available in sufficient detail to permit such a comparison. The data span noise environments ranging from the quiet of a wilderness area to the noisiest of airport and highway environments. At the lowest levels (L_{dn} around 40–55 dB), L_d is the controlling element in determining L_{dn}, because the nighttime noise level is so much lower than the daytime one. At higher L_{dn} levels (65–90 dB), the values of L_n are not much lower than those for L_d; thus, because of the 10-dB nighttime weighting, L_n will control the value of L_{dn}.

The choice of the 10-dB nighttime weighting in the computation of L_{dn} has the following effect: in low-noise level environments (below L_{dn} of approximately 55 dB) the natural drop in L_n values is approximately 10 dB, so that L_d and L_n contribute about equally to L_{dn}. However, in high-noise environments, the night noise levels drop relatively little from their daytime values. In these environments, the nighttime weighting applies pressure towards a round-the-clock reduction in noise levels if the noise criteria are to be met.

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APPENDIX B

CALIBRATION INFORMATION

It was the general practice during the survey to use more than one of the Sound Level Calibrators (SLCs) to provide a check, but only one was used as the standard SLC pressure reference signal for all acoustical equipment at each location.

In accordance with American National Standards, ANSI S1.4-1971 Review, and manufacturers' instructions, corrections were applied to calibrator readings as shown below:

CORRECTIONS TO CALIBRATOR READINGS

(all values in dB re 20 μPa [2.0×10^{-5} N/m^2])

	B&K 4220[a]	B&K 4230	GR 1986	GR 1567
Nominal frequency	250 Hz	1000 Hz	1000 Hz	1000 Hz
Sea level value	123.9	94	114	114
Elevation corrections:				
Site #1 (780 m)	122.9	94	113.5	113.5
Site #2 (380 m)	123.4	94	113.8	113.8
Site #3 (130 m)	123.7	94	113.9	113.9
A-weighting correction	-8.6	0	0	0

[a]Nominal value of B&K 4220 124 dB.

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APPENDIX C

MICROPHONE DATA SHEET AND RECORDER CONFIGURATION SHEETS

Table C-1. Microphone Configuration Log

Field System No.	Microphones and Accelerometers			Preamplifier/Sound Level Meter			Remarks
	Model No.	Serial No.	Sensitivity	Model No.	Serial No.	Low Freq. Cutoff (Hz)	
M1	B&K 4145	818913	49.5 mV per Pa	B&K 2631	807776	Set at 0.1 Hz	SERI System 3
M2	B&K 4145	818920	50.1 mV per Pa	B&K	807775	Set at 0.1 Hz	SERI System 1
M3	GenRad 1962-9601	6355		GenRad 1981-B	1336	"A" wt'd response ≈ 10 Hz	EPA #019349
M4	GenRad 1962-9601	6372		GenRad 1981-B	1348	"A" wt'd response ≈ 10 Hz	EPA #19348
M5	B&K 4145	564064	51.3 mV per Pa	B&K 2209 SLM	537246	Mike 1.3 Hz 2209 = 2 Hz	EPA #019084
VERT XDCR	B&K 8306	762772	0.973 V/m s^{-2} 9.53 V/g			DC-2500 Hz	VERT FM Channel
HORZ XDCR	B&K 8306	788204	0.980 V/m s^{-2} 9.59 V/g			DC-2500 Hz	HORZ FM Channel

Table C-2. Tape Recorder Configuration Log No. 1

Channel No.	FM or Direct	Parameter	Units	Normal Record Level	Remarks
1	FM	No. M1	dB linear	0.2 V peak	0.1 Hz to 625 Hz
2	FM	No. M3	dB(A)	0.1 V peak	DC voltage 10 mV/dB 30-80 dB
3	FM	No. M5	Linear wt	0.5 V peak	DC-5 kHz
4	Direct	No. M5	Linear wt	0.5 V peak	100 Hz to 19 kHz
5	FM	VERT XDCR	g's	0.1 V peak	Vertical DC-2500 Hz
6	FM	HORZ XDCR	g's	0.1 V peak	Horizontal DC-2500 Hz
7	FM	Voice	---	---	---

RACAL 7DS Tape Recorder, Model D7890-3, SIN 6119, SERI #110616

Site #1 (BPA Met Tower), 17-18 June 1980

Calibration: B&K 4230 SLC (SIN 830235) 93.6 dB @ 1000 Hz

Table C-3. Tape Recorder Configuration Log No. 2

Channel No.	FM or Direct	Field System	Units	Normal Record Level	Remarks
1	FM	No. M1	dB linear	0.2 V peak	0.1 Hz to 625 Hz
2	FM	No. M1	dB linear	0.5 V peak	0.1 Hz to 625 Hz
3	FM	No. M5	dB(A)	0.1 V peak	DC voltage 10 mV/dB
4	FM	Voice		Voice	30-80 dB

RACAL 4DS Tape Recorder, Model D7680-3, SIN 10232, SERI #110616

Site #1 (BPA Met Tower), 18-20 June 1980

Calibration: B&K 4320 SLC

Table C-4. Tape Recorder Configuration Log No. 3

Channel No.	FM or Direct	Field System	Units	Normal Record Level	Remarks
1	FM	No. M2	dB linear	0.2 V peak	0.1 Hz to 625 Hz
2	FM	No. M4	dB(A)	0.1 V peak	DC voltage 10 mV/dB 30-80 dB
3	FM	No. M5	Linear wt.	0.5 V peak	DC-5 kHz
4	Direct	No. M5	Linear wt.	0.5 V peak	100 Hz to 19 kHz
5	FM	Spare		Off	
6	FM	Spare		Off	
7	FM	Voice			

RACAL 7DS Tape Recorder

Site #2, 18-19 June 1980

Calibration: B&K 4230

Table C-5. Tape Recorder Configuration Log No. 4

Channel No.	FM or Direct	Parameter	Units	Normal Record Level	Remarks
1	FM	No. M2	dB linear	0.1 V peak	0.1 Hz to 625 Hz
2	FM	No. M4	dB(A)	0.1 V peak	DC voltage 10 mV/dB 30-80 dB
3	FM	No. M5	Linear wt.	0.5 V peak	DC to 5 kHz
4	Direct	No. M5	Linear wt.	0.5 V peak	100 Hz to 19 kHz
5	FM	Spare		Off	
6	FM	Spare		Off	
7	FM	Voice			

RACAL 4DS Tape Recorder

Site #3, 19-20 June 1980

Calibration: B&K 4230

APPENDIX D

COMMUNITY NOISE ANALYZER DATA SHEETS

Project No. MOD-2 Survey

Date: June 18, 1980

Sheet 1 of 4

- GEN RAD 1945 -

Community Noise Analyzer

Data Sheet

Test Data

	Run No.	1	2	3
	Dur.Hrs.	1	2	1
	From	3:00	4:00	6:00
	To	4:00	6:00	7:00
	L Value			
Switch Up	Max	53	61	61
	.1	49	56	55
	1	46	50	47
	10	42	44	42
	50	36	38	35
	90	32	33	31
	99	30	30	28
	Min	26	28	26
Switch Down	.5/24	45	48	46
	1/24	44	47	44
	8/24	38	40	37
	.5/8	43	46	43
	2	45	48	46
	5	43	46	44
	20	40	42	39
	Eq	38	41	39
	Dn			

Check List

Bat Test	Installed New Batt	
1st Run		x
2nd Run		x
3rd Run		x
Mic/Aux	MIKE	x
Weighting	"A" WT	x
Fast Slow	Fast	x
Data Erase		x
Cal.	114 dB	x
Altitude	2560 Feet	x
Set Time	2:45	
Clock Starts		
Start Clock		
Set Time Run	3:00	x
Begins		x
Enable Run		x
Display Off		x
Time Left Site	0830 Hrs.	

By: D. Miles

Remarks 1

Remarks 3

Remarks 2

Calibrator	GenRad 1986
Cal. Level	114 dB
Freq.	1000 Hz

Site Location: Goodnoe Hills, Washington

Located 100 feet south of the BPA met. tower.

Project No. MOD-2 Survey

Date: June 18-19, 1980

Sheet 2 of 4

- GEN RAD 1945 -

Community Noise Analyzer

Data Sheet

Test Data

	Run No.	1	2	3
	Dur.Hrs.	3	3	3
	From	2200	0100	0400
	To	0100	0400	0700
	L Value			
Switch Up	Max	82	80	69
	.1	74	53	60
	1	68	50	55
	10	57	39	50
	50	42	32	45
	90	33	28	39
	99	28	26	34
	Min	25	24	28
Switch Down	.5/24	65	48	53
	1/24	62	45	52
	8/24	46	34	46
	.5/8	60	43	51
	2	65	48	54
	5	61	44	51
	20	51	35	48
	Eq	55	40	47
	Dn			

Check List

Bat Test		
1st Run		x
2nd Run		x
3rd Run		x
Mic/Aux	MIKE	x
Weighting	"A" WT	x
Fast Slow	Fast	x
Data Erase		x
Cal.	114 dB/94dB	
Altitude		
Set Time		
Clock Starts		
Start Clock		
Set Time Run	2200	
Begins		
Enable Run		
Display Off		x
Time Left Site	0800 06/19/80	

By: McKenna, Garrelts, Miles

Remarks 1
No Wind Screen this 3hr run

Remarks 3
Wind Screen on

Remarks 2 Wind Screen on

Calibrator GenRad 1986 & B&K 4230

Cal. Level 94dB & 114 dB

Freq. 1000 Hz

Site Location: Measurement Site #2- Goodnoe Hills, Washington

Project No. MOD-2 Survey

Date: June 19, 1980

Sheet 3 of 4

- GEN RAD 1945 -

Community Noise Analyzer

Data Sheet

Test Data

	Run No.	1	2	3
	Dur.Hrs.	4	4	
	From	0830	1230	
	To	1230	1630	
	L Value			
Switch Up	Max	77	88	
	.1	59	73	
	1	52	58	
	10	41	41	
	50	33	33	
	90	29	29	
	99	27	27	
	Min	25	24	
Switch Down	.5/24	49	50	
	1/24	45	45	
	8/24	35	36	
	.5/8	43	43	
	2	49	50	
	5	44	44	
	20	37	38	
	Eq	41	51	
	Dn	N/A	N/A	

Check List

Bat Test	Inst. new Batt.	
1st Run		x
2nd Run		x
3rd Run		x
Mic/Aux	MIKE	x
Weighting	"A" WT	x
Fast Slow	Fast	x
Data Erase		x
Cal.		x
Altitude		x
Set Time		
Clock Starts	8:24	x
Start Clock		
Set Time Run	8:30	x
Begins		x
Enable Run		x
Display Off		x
Time Left Site	1900 Hr.	x

By: D. Miles

Remarks 1 Didn't fully set up before run started- i.e. maximum L's may be affected

Remarks 3 No problems with Data Run.

Remarks 2 No problems with Data Run

Calibrator	B&K 4230
Cal. Level	94 dB
Freq.	1000 Hz

Site Location: MOD-2 Site, ~600 ft. North of Met Tower Site

Project No. MOD-2 Survey

Date: June 19-20, 1980

Sheet 4 of 4

- GEN RAD 1945 -

Community Noise Analyzer

Data Sheet

Test Data

		1	2	3
	Run No.	1	2	3
	Dur.Hrs.	2	3	6
	From	2000	2200	0100
	To	2200	0100	0700
	L Value			
Switch Up	Max	86	75	108
Switch Up	.1	65	67	80
Switch Up	1	57	58	79
Switch Up	10	48	46	73
Switch Up	50	39	39	40
Switch Up	90	35	36	36
Switch Up	99	31	35	34
Switch Up	Min	28	33	30
Switch Down	.5/24	55	57	78
Switch Down	1/24	53	53	77
Switch Down	8/24	41	40	47
Switch Down	.5/8	51	49	76
Switch Down	2	55	57	78
Switch Down	5	53	51	76
Switch Down	20	44	42	59
Switch Down	Eq	47	47	68
Switch Down	Dn			

Check List

Bat Test		
1st Run		x
2nd Run		x
3rd Run		x
Mic/Aux	MIKE	x
Weighting	"A" WT	x
Fast Slow	Fast	x
Data Erase		x
Cal.		x
Altitude	445'	x
Set Time		
Clock Starts		x
Start Clock		
Set Time Run	0800	x
Begins		x
Enable Run		x
Display Off		x
Time Left Site	1030 06/20/80	x

By: D. Miles

Remarks 1

Remarks 3 At 4:30 placed plastic cover on analyzer and bag over mike-at 6:40 found mike down-presumably by a bird-rain affected results.

Remarks 2

Calibrator GR 4230 S/N 542220

Cal. Level 94 dB

Freq. 1 K Hz

Site Location: Measurement site #3; Goldendale, Washington